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A COMPUTER PROGRAM FOR CALCULATING EXTERNAL THERMAL-RADIATION HEAT LOADS AND TEMPERATURES OF SPACECRAFT ORBITING THE PLANETS OR THE MOON

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ABSTRACT

A versatile computer program to predict the thermal history of a spacecraft orbiting a celestial body is documented. With this program, all external thermal-radiation heat loads, thin-skin temperatures, or both, are computed for a spinning or oriented spacecraft as a function of orbit position and time. The generalized program applies to any spacecraft configuration. A major feature of the program is its applicability to effects resulting from the extreme surface temperature of the Moon.

Major sections are entitled "Heat-Transfer Theory," "Celestial Mechanics Theory: Coordinate Systems," "Numerical Analysis," "Digital Computer Program," and "Computer Program Application." In addition, sample problems, a complete program listing, and a program user's guide explaining the data input format are included.

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A COMPUTER PROGRAM FOR CALCULATING EXTERNAL THERMAL-RADIATION HEAT LOADS AND TEMPERATURES OF SPACECRAFT ORBITING THE PLANETS OR THE MOON

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SUMMARY

A computer program to predict the thermal history of a spacecraft in orbit about a celestial body is presented. The program, associated information required for use of the program, and the theory and methods used to develop the program are included. The thermal environment predicted is comprised of all external thermal-radiation heat loads, thin-skin temperatures, or both, for a spinning or oriented space vehicle as a function of orbit position and time. Manned and unmanned satellites and spacecraft or other objects in orbit oriented on the Sun, the Moon, Earth, or a planet other than Earth are within the capability of the program to predict the thermal history of oriented vehicles. A maximum of 200 vehicle surface elements can be analyzed by the computer program. The constant or temperature-dependent thermophysical properties of each element are obtained from one of eight optical-properties tables and from one of eight substrate-properties tables.

The program is generalized so that calculations can be performed for any specified element location. The program does not incorporate details of spacecraft configuration, and the shadowing of one portion of a spacecraft by another spacecraft or by a portion of the same spacecraft is not considered.

A significant feature of the program is the ability to consider the effects of extreme lunar-surface temperature variations on a lunar-orbital spacecraft. The results from a hypothetical lunar-orbital mission confirm the value of this feature of the program by displaying errors of ±100° F, on the erroneous assumption that the temperature of the Moon is constant along the surface.

INTRODUCTION

Because of the extreme temperature environment of space and because of the critical limits in the operating temperatures of spacecraft materials, thermal control is an important consideration in the development of spacecraft and components. With the absence of an atmosphere in space, the mode of heat transfer between the spacecraft and its natural environment is thermal radiation. Thus, to insure satisfactory thermal design, a means of accurately determining the spacecraft external radiative environment is required. To determine the environment readily and economically for parametric design analysis, a computer program designed to continuously determine external heat fluxes and temperatures as a vehicle orbits a planet was developed by Midwest Research Institute (MRI) for the NASA Manned Spacecraft Center (MSC) under contract NAS 9-1059. To improve the efficiency, capabilities, and input-output formats of the program, several modifications have been added to the program by NASA MSC. This report is a description of the program developed by MRI with the NASA MSC modifications.

The program, which is documented in the Univac 1108 FORTRAN V language, is a generalized analytical tool capable of determining solar, planetary, and albedo (the solar heat reflected from a planet and its atmosphere) heat fluxes, temperatures, or both. Heat fluxes are obtained for spinning vehicles or for a large number of infinitesimal vehicle surface elements for a vehicle that is planet or sun oriented. To determine the quantity of incident thermal radiation on an elemental area of the vehicle, the angle of incidence is determined first by coordinate transformation. Using the angle of incidence, the configuration factors are obtained from a stored table of radiation-configuration-factor values. The table was developed from a previous study in which the numerical integration of the applicable equations was accomplished. The configuration factors are then used to calculate the component parts of the incident flux. The transient temperatures are calculated by numerical integration of the general differential equation obtained by performing a heat balance about the elemental area. Although the program is capable of analyzing orbits about all planets except Pluto, special emphasis has been placed on problems associated with lunar missions. (Sufficient planetary data are not available to analyze Pluto orbits.) The approach used in analyzing spacecraft heating effects from the extreme surface temperature gradient of the Moon is known, at present, to be applicable only to the Moon. The computer program is written, therefore, so that its use is restricted to lunar orbits. However, if celestial bodies other than the Moon exhibit temperature variations similar to those of the Moon, the program can be modified accordingly, since this part of the program and the discussion within this report are generalized.

SYMBOLS

A	area
a	semimajor axis of orbit ellipse
a_s	semimajor axis of the semiellipse traced by the shadow of the planet

B boundary on accumulated errors

b semiminor axis of orbit ellipse

b_s semiminor axis of the semiellipse traced by the shadow of the planet

C_1, C_2 variable coefficient

C_p specific heat

c distance between the center and focus of an ellipse

D distance between the orbiting vehicle and the center of the planet

DEC declination (latitude of the Sun with respect to the X_c-, Y_c-, and Z_c-axes)

d distance between the orbiting vehicle and the planet element

E eccentric anomaly

E_c, E_p emissive power, appendix B

E_n total error caused by numerical integration

e eccentricity of orbit ellipse

e_{ro} accumulated effect of round-off error over n steps

$e_{t,a}$ accumulated truncation error over steps 1 to n-1

$e_{t,n}$ one-step truncation error (the error caused by approximation over step n)

F_i radiation configuration factor, $i = 1, 2, 3, 4$

G gravitational constant

H altitude

h vehicle skin thickness

I intensity of radiation

i inclination of orbital plane

ℓ distance between center of areas exchanging radiant energy

M_p	planet mass
P	period (time to complete one orbit)
Q_g	internal heat generation
q	heat flux
R	solar reflectance of celestial body (albedo)
RA	right ascension (longitude of Sun with respect to the X_c-, Y_c-, and Z_c-axes)
r_o	orbit radius
r_p	planet radius
r_s	shadow radius
r_v	radius of a spherical vehicle
S	solar constant
T	temperature
T_m	minimum planet temperature (dark side of planet)
T_p	average planet temperature
t	time
V	volume
X, Y, Z	coordinate axes
α	angle $\leq 180°$ between the planet-Sun line and the X_p-axis
α_p	absorptance of vehicle material with respect to planet-emitted radiation
α_r	absorptance of the receiving surface
α_s	absorptance of vehicle material with respect to solar radiation
β	angle $\leq 180°$ between the planet-Sun line and the Z_p-axis, or the angle between a planet element-Sun line and the planet element normal

γ angle $\leq 180°$ between the planet-Sun line and the Y_p-axis

$\Delta\phi$ integration step-size as specified in input data; a smaller increment may be chosen by the computer program

δ angle between the vehicle-Sun line and the vehicle-vehicle element line

ϵ angle between the vehicle element-vehicle line and the vehicle-planet line

ϵ_e emittance of emitting surface

ϵ_p emittance of planet

ϵ_v emittance of vehicle material

θ angle between the planet-element line and the planet-vehicle line

θ_s angle between the Sun-planet line and the planet-vehicle line

Λ' angle measured from the X_v-axis $\left(\text{towards } Y_v\right)$ to the projection of the vehicle-vehicle element line on the X_v-Y_v plane

Λ_s angle measured from the X_v-axis $\left(\text{towards } Y_v\right)$ to the projection of the Sun-vehicle line on the X_v-Y_v plane

λ angle between the vehicle-planet line and a vehicle-planet element line

ρ density

Σ angle between the X_p-axis and the projection of the Sun-planet line on the X_p-Y_p plane

σ Stefan-Boltzmann constant

♈ vernal equinox (an intersection of the Earth equator and the ecliptic)

ϕ true anomaly

ϕ_c angle between the vehicle-planet-Sun plane and the vehicle element-vehicle-planet plane

ϕ_{in} value of ϕ, where the vehicle passes into the shadow of the planet

ϕ_{out} value of ϕ, where the vehicle passes out of the shadow of the planet

ϕ_r angle between a normal to dA_r and a line from dA_r to A_e

$\chi = \frac{X_p}{a}$

ψ angle shown in figure B-1

Ω longitude of ascending node

Ω' angle between the Z_v-axis and the vehicle-vehicle element line

$\underline{\Omega}$ autumnal equinox (an intersection of the Earth equator and the ecliptic)

Ω_s angle between the Z_v-axis and the Sun-vehicle line

ω argument of perifocus

Subscripts:

c celestial

e emitting body

n specified number of computation steps

o initial condition

p planet

r receiving body

s Sun

v vehicle

ASSUMPTIONS

The formulation of a practical computer program for the calculation of orbital heat fluxes and temperatures requires the use of simplifying assumptions. (These assumptions, none of which appreciably affect the accuracy of the program or the applicability of the program to the intended purpose, are summarized in the following items. It is necessary to evaluate each assumption with respect to application of the program to assure that each assumption is acceptable.

1. Each element is assumed to be thermally isolated from all others; that is, conduction between nodes is not considered. However, the program output allows the

heat loads to each element as a function of time to be loaded conveniently into a heat-conduction program. If desired, the thermal-environment-prediction program may be modified so that the heat loads are punched on cards in a specific format for use as direct input to a heat-conduction program. Programing has been done in FORTRAN V to facilitate such modifications.

2. Conduction and convection between the vehicle and its surroundings are neglected. This assumption is generally valid, since orbits are usually well above any significant atmosphere.

3. Perturbations are neglected. In cases in which perturbations have a significant effect upon the orbit, the mission should be subdivided into two or more segments, and each segment should be run as a separate case. The independently obtained, perturbed orbit parameters in each case are then reentered as new input.

4. The position of the Sun with respect to the orbit is assumed to be fixed. This assumption is reasonable, unless the flight duration becomes an appreciable portion of the planet period. If this occurs, the mission can be subdivided and run as several cases, each with the appropriate coordinates of the Sun specified as input data.

5. The solar constant is assumed to be independent of the vehicle orbit position. Since the semimajor axis of a vehicle orbit is generally small compared to the distance from the Sun to the planet, solar radiation is essentially constant throughout a given orbit.

6. Planet data, such as albedo and mass, are stored internally and are assumed to be invariant. Although these data are essentially constant, the accepted values are occasionally refined. If the program data are to be refined accordingly, a section of the program must be changed and recompiled. This disadvantage of requiring refinement and recompilation is offset by the convenience of not having to include planet properties in the input data each time a case is to be run.

7. The shadow of the planet is assumed to be cylindrically shaped, and penumbral effects are neglected. The method of determining the intersection of the orbit and the shadow is described in appendix A. The resulting errors in Sun-shade point and heat-load determinations are negligible even for large orbits.

8. The thermal radiation discussed in this report is assumed to be diffuse. This assumption is reasonable, except for cases in which the radiation is emitted by a polished vehicle surface.

9. Planet albedo is assumed to be independent of surface position or features. An average value is used because the local values depend on such variables as clouds and other atmospheric conditions that are difficult to predict.

10. Internally generated heat is assumed to be uniformly distributed over the applicable vehicle surface. If this assumption is not reasonable for any case, the internal heat and corresponding surface element should be subdivided until an acceptable assumption is obtained.

11. On the sunlit side, the Moon is assumed to absorb and emit energy as a smooth sphere. With this assumption, the absorbed energy available for emission is proportional to $\cos \beta$, and the lunar-surface temperature is proportional to $\cos^{1/4} \beta$. (A definition of β is provided in appendix B.) Based on a thorough survey of the literature related to the discussion in this report, this assumption was found to be the most realistic and practical approach to handling the extreme temperature gradients over the lunar surface.

12. The temperature T_m of the dark side of the Moon is assumed to be constant. This assumption is considered reasonable, since the heat radiated from the back side of the Moon is less than 1 percent of the heat radiated at the subsolar point, and variations in T_m introduce negligible changes in the heat flux q_p.

13. The vehicle absorptance of reflected solar radiation is assumed to be the same as the vehicle absorptance of direct solar radiation. Although the spectral characteristics of solar radiation are probably changed when solar radiation is reflected, it is believed that this change has little effect on the solar absorptance α_s.

HEAT-TRANSFER THEORY

Fundamental heat-transfer theory has been used to determine the impinging heat loads and the transient surface temperatures of orbiting spacecraft. Heat-transfer theory and equations applicable to the discussion in this report are summarized in the following paragraphs of this section. Detailed derivations are given in appendixes A to C.

Heat Loads

A vehicle orbiting in a vacuum is externally heated by thermal radiation, principally from the planet being orbited and from the Sun. (For convenience, throughout this report, the term "planet" applies to any planet or the Moon.) The amount of heat originating from other celestial bodies is generally negligible. Most of the solar radiation comes directly from the Sun. The remainder is reflected by the planet before impinging upon the vehicle surface and is referred to as albedo heat flux. Solar, planet, and albedo heat fluxes are illustrated in figure 1.

Since an orbiting vehicle may spend a significant portion of each orbit in the shadow of a planet, shielded from both direct and reflected solar radiation, it is necessary to determine the part of the orbit during which the vehicle is shaded. The method used to determine the intersection of the orbit and the shadow is described in appendix A.

The heat emitted by a planet depends on the surface temperature of the planet. If the planet is shrouded with a heavy atmospheric blanket, the surface temperature is relatively uniform because of convection and conductance heat transfer and can be considered constant. It is impractical, if not impossible, to account for temperature

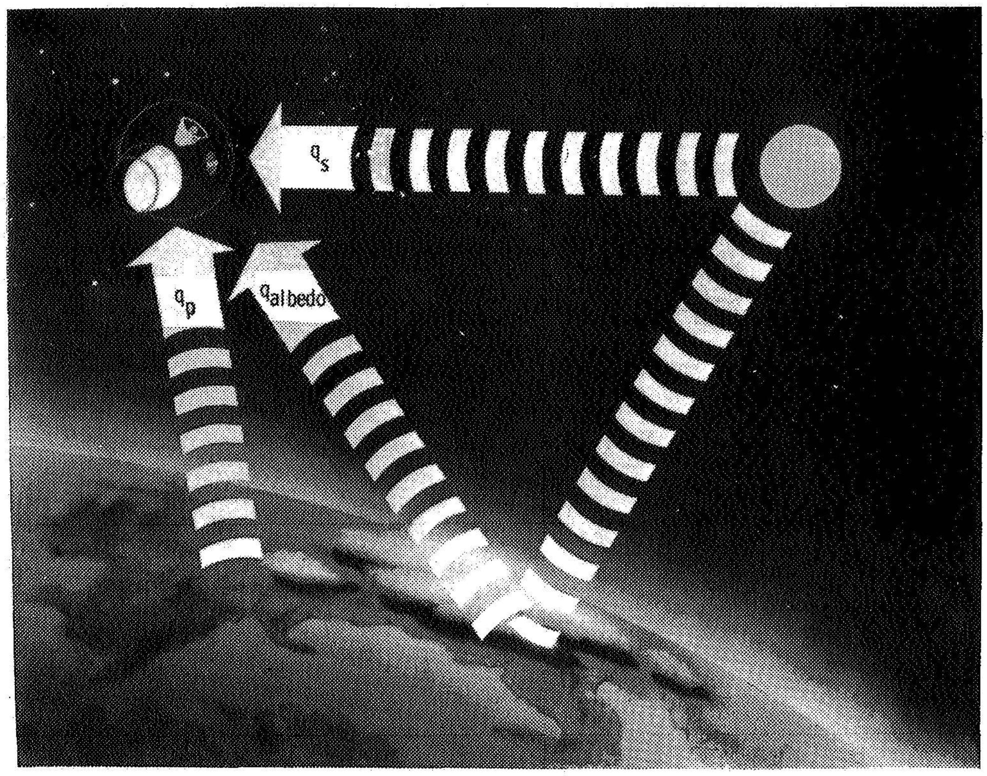


Figure 1. - Principal external heat loads.

deviations from the average, since the deviations are functions of such intangibles as wind, snow, cloud coverage, and atmospheric activity.

If a celestial body (for example, the Moon) has a negligible atmosphere and a nonconducting surface, the surface temperature gradients may be large and should therefore be determined. Fortunately, the factors that cause the extreme variations also make it possible to determine the surface temperature distribution with reasonable accuracy.

External heat loads are summarized for spinning and oriented vehicles as functions of altitude and of the parameters θ_s, Ω', Λ', Ω_s, Λ_s, δ, ϵ, and ϕ_c. Complete derivations are given in appendix B.

Radiation impinging on spinning vehicles. - The period of rotation of a spinning vehicle is assumed to be fast enough for the impinging thermal radiation to be uniformly distributed over the vehicle surface. Solar radiation per cross-sectional area A_v striking a spinning vehicle is

$$\frac{q_s}{A_v} = S \tag{1}$$

where the solar constant S is inversely proportional to the square of the distance from the Sun.

Radiation received from a constant-temperature planet $\left(T_p = \text{constant}\right)$ is given in equation (B16d) of appendix B as

$$\frac{q_p}{A_v} = 2S(1 - R)F_1 \qquad T_p = \text{constant} \tag{2a}$$

where

$$F_1 = \frac{1 - \left[1 - \left(\frac{r_p}{D}\right)^2\right]^{1/2}}{4} \tag{2b}$$

The corresponding heat rate for a variable-temperature planet $\left(T_p \neq \text{constant}\right)$ is expressed in equation (B30d) as

$$\frac{q_p}{A_v} = 8S(1 - R)F_2 \qquad T_p \neq \text{constant} \tag{3a}$$

where

$$F_2 \approx \left\{\frac{1 - \left[1 - \left(\frac{r_p}{D}\right)^2\right]^{1/2}}{4}\right\} \cos \theta_s \tag{3b}$$

Equation (3b) closely approximates the exact radiation configuration factor, as demonstrated in figure B-5 of appendix B.

For the condition when $\theta_s > 90°$, F_2 is set equal to zero by the computer program, since the vehicle is in the planet shadow and, therefore, the sun does not emit radiation to the vehicle.

The temperatures of the dark sides of variable-temperature planets are low, but the temperatures are high enough for the emission of some heat. According to equation (B33), this emitted heat can be expressed by

$$\frac{q_p}{A_v} = 8\sigma T_m^{\ 4} F_1 \qquad T_p \neq \text{constant (dark side of planet)} \tag{4}$$

where F_1 is defined in equation (2b), σ is the Stefan-Boltzmann constant, and T_m is the average dark-side or minimum planet temperature. The value of T_m for the Moon (186° R) is stored internally in the computer program.

The albedo heat flux impinging on a spinning vehicle is given in equation (B38d) as

$$\frac{q_{albedo}}{A_v} = 8SRF_2 \tag{5}$$

where F_2 is defined in equation (3b).

Radiation impinging on oriented vehicles. - An object is planet oriented if the line connecting the vehicle and planet center passes through the same vehicle surface element for all positions in the orbit path. Similarly an object is Sun oriented if the vehicle-Sun line passes through the same surface element at all times.

The incident heat flux on an oriented vehicle can vary from one surface position to another. Therefore, expressions for the heat flux to any surface element must be derived. The equations developed in appendix B are applicable to either Sun-oriented or planet-oriented vehicles, provided the required independent variables (for example, δ) are defined for each orientation, as described in the section of this report entitled "Celestial Mechanics Theory: Coordinate Systems." The following heat-flux expressions are developed for a typical surface element located with respect to the vehicle coordinate system by the angles Λ' and Ω'.

Solar radiation impinging on a surface element is

$$\frac{q_s}{A_v} = S \cos \delta \qquad \delta \leqq 90° \tag{6a}$$

If δ is greater than 90° (that is, $\cos \delta < 0$), the element does not receive radiation from the Sun, therefore

$$\frac{q_s}{A_v} = 0 \qquad \delta > 90° \tag{6b}$$

The heat flux from a constant-temperature planet is given in equation (B46c) as

$$\frac{q_p}{A_v} = \frac{S(1 - R)F_4}{4} \qquad T_p = \text{constant} \tag{7}$$

where F_4 is a function of altitude H and the variables ϕ_c and ϵ, which are illustrated in figure 2. Values of F_4 have been evaluated by numerical integration over the applicable ranges of ϕ_c and ϵ and to an altitude for which the radiation configuration factor, and therefore the planet heat, is negligible (an altitude of approximately five planet radii). (For all values of ϕ_c and ϵ, F_4 is set equal to zero when $F_4(H \approx 5r_p)/F_4(H=0) \leq 0.015$). A table of over 2500 values representing the function $F_4 = F\ \phi_c, \epsilon, H$ has been incorporated into the permanent data deck of the computer program.

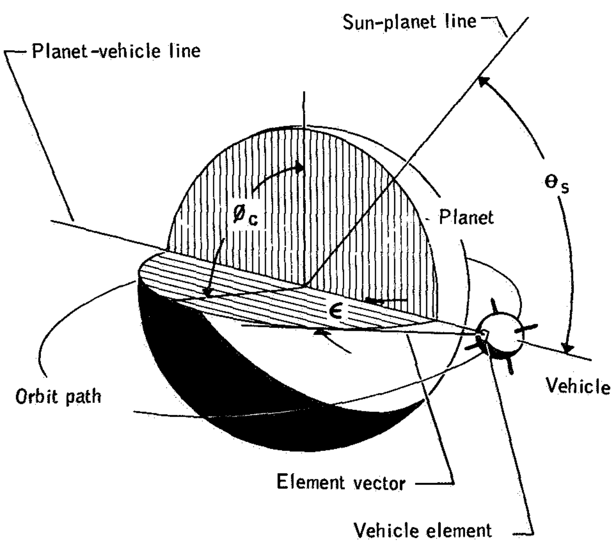


Figure 2. - Angular variables for determining radiation configuration factors of oriented vehicles.

The heat flux from a variable-temperature planet is given in equation (B42c) as

$$\frac{q_p}{A_v} = S(1 - R)F_3 \qquad T_p \neq \text{constant} \tag{8}$$

where F_3 is a function of H, ϕ_c, ϵ, and θ_s. The variable θ_s is the angle between the vehicle, the planet, and the Sun, as shown in figure 2. In appendix B, the relationship that exists between F_3 and F_4 is described in detail.

The impinging heat from the dark side of the variable-temperature planet is given in equation (B47) as

$$\frac{q_p}{A_v} = \sigma T_m{}^4 F_4 \qquad T_p \neq \text{constant (dark side of planet)} \tag{9}$$

The albedo heat flux irradiating an oriented-vehicle element is expressed in equation (B50c) as

$$\frac{q_{albedo}}{A_v} = SRF_3 \tag{10}$$

Transient Temperatures

The transient temperature of an orbiting vehicle is obtained by conducting a heat balance on the vehicle and by solving the resulting differential equation. For this analysis, each surface element of an oriented vehicle is considered to be thermally isolated from all other elements.

The general governing differential equation is

$$\frac{dT}{dt} = \frac{1}{\rho C_p V}\left(q_s\alpha_s + q_{albedo}\alpha_s + q_p\alpha_p + q_{internal} - q_{out}\right) \tag{11}$$

where ρ and C_p are the density and the specific heat, respectively, of the vehicle material and V is the volume being analyzed. The term $q_{internal}$ represents the amount of internally generated heat that is absorbed by the vehicle skin. It is assumed that $q_{internal}$ is dissipated uniformly over the entire external area of the vehicle if it is spinning or over the surface element if the spacecraft is planet or Sun oriented. Internally generated heat is expressed as

$$q_{internal} = Q_g \tag{12}$$

The negative term q_{out} in equation (11) is the heat emitted by the vehicle and is given by

$$\frac{q_{out}}{A_v} = \sigma\epsilon_v T^4 \tag{13}$$

where T is the instantaneous surface temperature, ϵ_v is the emittance of the material at temperature T, and A_v is the total emitting-surface area. Introducing the appropriate heat terms into equation (11) gives the governing temperature differential equations as follows. For a spinning vehicle orbiting a constant-temperature planet

$$\frac{dT}{dt} = \frac{1}{\rho C_p h}\left[\frac{S\alpha_s}{4} + 2SR\alpha_s F_2 + \frac{S(1 - R)\alpha_p F_1}{2} + Q_g - \sigma\epsilon_v T^4\right] \tag{14a}$$

where h is skin thickness and α_s and α_p are the solar and planet absorptance of the material, respectively.

For a spinning vehicle orbiting a variable-temperature planet

$$\frac{dT}{dt} = \frac{1}{\rho C_p h}\left[\frac{S\alpha_s}{4} + 2SR\alpha_s F_2 + 2S(1 - R)\alpha_p F_2 + Q_g - \sigma\epsilon_v T^4\right] \tag{14b}$$

or

$$\frac{dT}{dt} = \frac{1}{\rho C_p h}\left(\frac{S\alpha_s}{4} + 2SR\alpha_s F_2 + 2\sigma\alpha_p T_m{}^4 F_1 + Q_g - \sigma\epsilon_v T^4\right) \tag{14c}$$

depending on whether the vehicle is above the sunlit or the dark side of the planet, respectively. Near the terminator, the larger value of dT/dt from equations (14b) and (14c) is used.

For an oriented vehicle orbiting a constant-temperature planet

$$\frac{dT}{dt} = \frac{1}{\rho C_p h}\left[S\alpha_s \cos \delta + SR\alpha_s F_3 + \frac{S(1 - R)\alpha_p F_4}{4} + Q_g - \sigma\epsilon_v T^4\right] \tag{14d}$$

For an oriented vehicle orbiting a variable-temperature planet

$$\frac{dT}{dt} = \frac{1}{\rho C_p h}\left[S\alpha_s \cos \delta + SR\alpha_s F_3 + S(1 - R)\alpha_p F_3 + Q_g - \sigma\epsilon_v T^4\right] \tag{14e}$$

or if the oriented vehicle is above the shaded half of the planet

$$\frac{dT}{dt} = \frac{1}{\rho C_p h}\left(S\alpha_s \cos \delta + SR\alpha_s F_3 + \sigma T_m^{\ 4}\alpha_p F_4 + Q_g - \sigma\epsilon_v T^4\right) \tag{14f}$$

Near the terminator, equations (14e) and (14f) are both evaluated, but the smaller value of dT/dt is discarded.

Equations (14a) to (14f) are of the form

$$\frac{dT}{dt} = C_1 - C_2 T^4 \tag{15}$$

where C_1 and C_2 are variable coefficients. Both t and $\emptyset$ must be known in order to evaluate C_1 and C_2; thus, an expression relating t and $\emptyset$ is required. The necessary relationship is derived by first writing t as a function of the eccentric anomaly E in accordance with Kepler's laws of planetary motion.

$$t = \frac{(E - e \sin E)P}{2\pi} \tag{16}$$

where t and E are measured from perigee. The period P is

$$P = 2\pi\left(\frac{a^3}{GM_p}\right)^{1/2} \tag{17}$$

where G is a gravitational constant and M_p is the planet mass.

Time can now be expressed as a function of ϕ by combining equations (16) and (22).

$$t = \frac{2\tan^{-1}\left[\left(\tan\frac{\phi}{2}\right)\left(\frac{a-c}{b}\right)\right] - e\sin\left\{2\tan^{-1}\left[\left(\tan\frac{\phi}{2}\right)\left(\frac{a-c}{b}\right)\right]\right\}}{2\pi P^{-1}} \tag{18}$$

Equation (18) can be solved readily for t; however, an iterative solution is required in order to obtain the solution $\phi = f(t)$. Consequently, ϕ has been selected as the independent variable. This is indicated in equation (15) as

$$\frac{dT}{d[t(\phi)]} = C_1 - C_2T^4 \tag{19}$$

Equation (19) does not yield a closed-form solution, but can be solved numerically. The procedure for numerically integrating equation (19) is described in the section of this report entitled "Numerical Analysis."

CELESTIAL MECHANICS THEORY: COORDINATE SYSTEMS

Four locations must be specified for the determination of vehicle heat loads:

1. The location of each vehicle surface element being analyzed (not applicable to spinning satellites)

2. The location of the vehicle with respect to the planet being orbited

3. The celestial location of the vehicle

4. The location of the Sun with respect to the planet being orbited

The required locations can be obtained in terms of vehicle, planet, and celestial coordinate systems. These systems are identified throughout this report by the following notation:

1. Vehicle coordinates — X_v, Y_v, and Z_v

2. Planet coordinates — X_p, Y_p, and Z_p

3. Celestial coordinates — X_c, Y_c, and Z_c

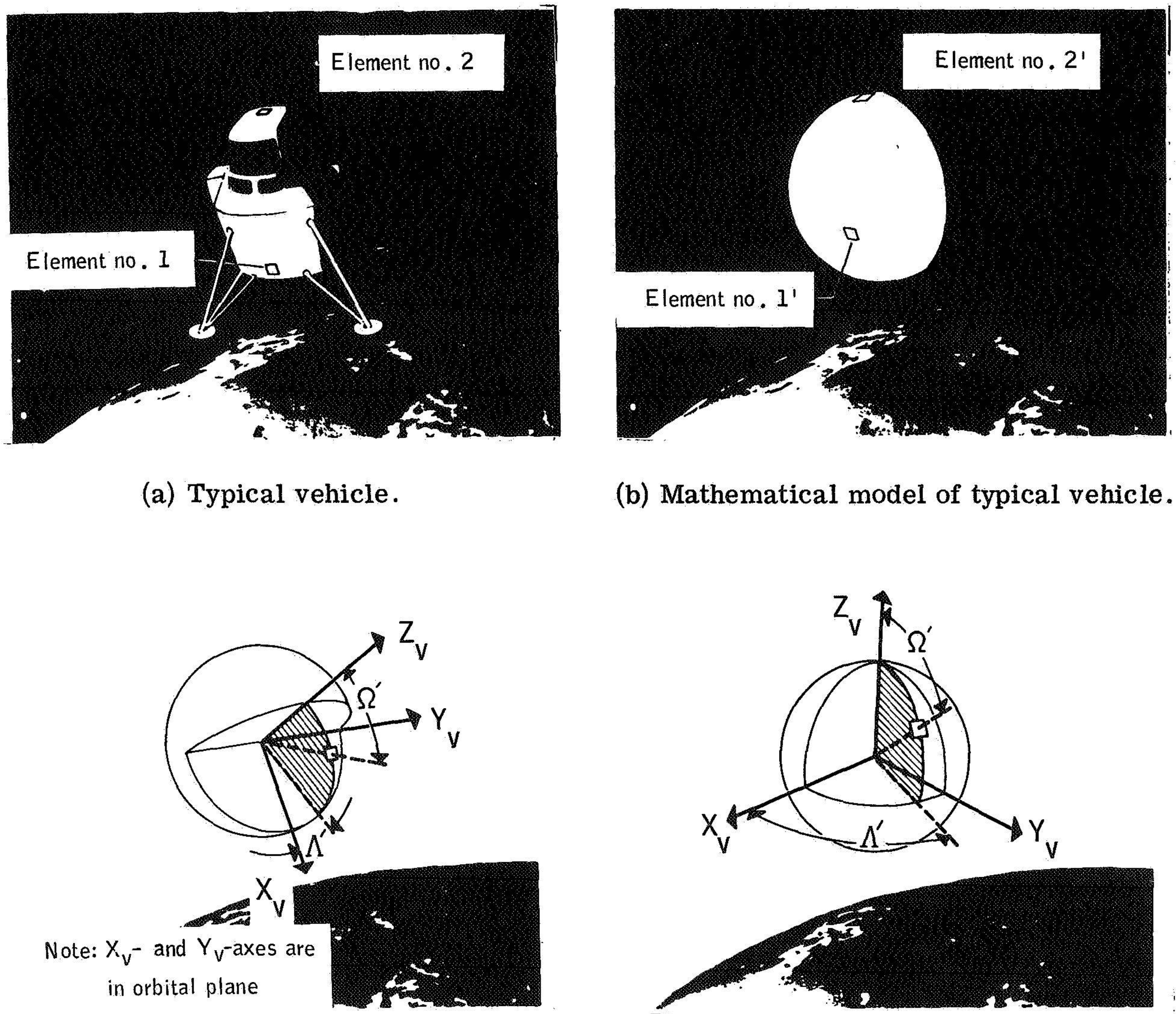
The three coordinate systems are summarized in table D-I of appendix D.

Vehicle Coordinates

For a spinning vehicle, no distinction is required between surface elements; and coordinates X_v, Y_v, and Z_v are not applicable, since it is assumed that the vehicle is spinning fast enough that impinging thermal radiation is uniformly distributed over the vehicle surface.

For an oriented vehicle, however, the incident heat flux can vary considerably from one surface position to another. For example, element no. 1 on the planet-oriented vehicle shown in figure 3 receives heat emitted by the planet, and element no. 2 does not receive heat emitted by the planet. Consequently, a coordinate system for the location of each element being analyzed is required for the thermal analysis of oriented spacecraft. The vehicle coordinates used are illustrated in figure 3. The complex configuration shown in figure 3(a) is first replaced with a spherical mathematical model, as shown in figure 3(b). Surface element no. 1' and surface element no. 2' on the sphere are selected so that they have the same space orientation as vehicle element no. 1 and vehicle element no. 2. If the orbiting body is planet oriented, surface positions on the sphere are defined with respect to the coordinate system illustrated in figure 3(c). The origin is at the center of the sphere, and the X_v-axis is directed toward the planet center of mass. The Y_v-axis is at right angles to the X_v-axis in the orbital plane, with the positive direction opposite the vehicle velocity vector. The direction of vehicle travel is always in the same direction as the movement when the X_p-axis is rotated into the Y_p-axis through the smallest angle. The Z_v-axis is normal to the orbital plane in a direction such that X_v, Y_v, and Z_v form a right-handed coordinate system. Surface elements are defined by the angles Λ' and Ω', as shown in figures 3(c) and 3(d). The angle Λ' is measured from the X_v-axis $(\text{toward } Y_v)$ to the projection of the element on the X_v-Y_v plane ($0° \leq \Lambda' < 360°$); Ω' is measured from the Z_v-axis to the element ($0° \leq \Omega' \leq 180°$).

The technique of locating elements on the vehicle with the two angles Λ' and Ω' can be likened to the method used to locate a point on Earth by using the two angles of longitude and latitude. If the orbiting body is Sun oriented, surface points or features are located with respect to the system shown in figure 3(d). The origin is again at the center of the sphere, but the X_v-axis is directed toward the Sun. The Y_v-axis is in the orbital plane at right angles to X_v. The Z_v-axis is always in the same hemisphere as the Z_p-axis and completes the orthogonal system. For the special case in which the projection of the X_v-axis on the orbital plane is a point, the vehicle coordinate system should be set up as described previously. However, to eliminate ambiguity, Y_v is chosen to be in the same direction as Y_p. Surface elements are described by the coordinates Λ' and Ω', as before.



(a) Typical vehicle.

(b) Mathematical model of typical vehicle.

(c) Mathematical model (planet oriented).

(d) Mathematical model (Sun oriented).

Figure 3. - Vehicle coordinate system for typical spacecraft.

Planet Coordinates

Before computing the impinging heat loads emitted or reflected by the planet, the location of the vehicle with respect to the planet being orbited must be specified. The orbits and planets shown in figures 4(a) and 4(b) are the same. However, in figure 4(b), the orbit is shown rotated into the plane of the page. Superimposing the X_p- and Y_p-axes (planet coordinates) onto the orbital plane simplifies the equations of motion by reducing the problem from three dimensions to two. The position of the vehicle can be defined in the two-dimensional system by either polar or Cartesian coordinates.

The polar coordinates of a point on the orbit are the true anomaly ϕ and the distance D from the principal focus, or center of force, to the vehicle. The distance is given by

$$D = a(1 - e \cos E) \tag{20}$$

where a is the semimajor axis, e is the eccentricity of the orbit, and E is the eccentric anomaly. The variables e and E are formulated as

$$e = \frac{\left(a^2 - b^2\right)^{1/2}}{a} = \frac{c}{a} \tag{21}$$

and

$$E = 2 \tan^{-1}\left[\left(\tan \frac{\phi}{2}\right)\left(\frac{a - c}{b}\right)\right] \tag{22}$$

where b is the semiminor axis and c is the distance between the center and the focus of the ellipse.

The Cartesian coordinates X_p and Y_p of a point on the orbit are expressed as

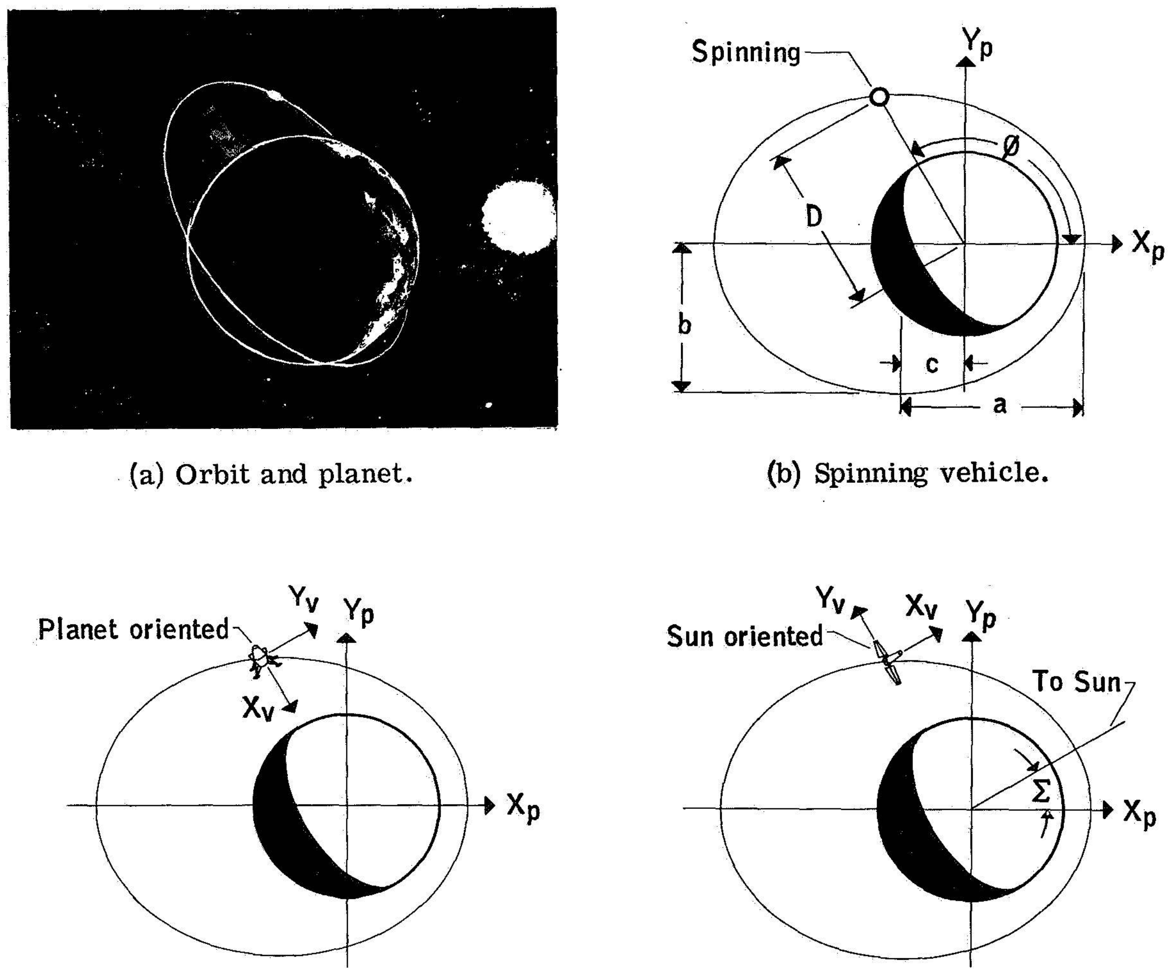
$$X_p = a(\cos E - e) \tag{23}$$

and

$$Y_p = a\left(1 - e^2\right)^{1/2} \sin E \tag{24}$$

Vehicle coordinates for a planet-oriented orbiting body superimposed on the planet coordinate system are shown in figure 4(c). As the vehicle makes one counterclockwise revolution about the planet, the X_v- and Y_v-axes are similarly rotated about the Z_v-axis.

The vehicle and planet coordinates for Sun-oriented satellites are illustrated in figure 4(d). The X_v-Y_v plane is generally not in the X_p-Y_p plane, since X_v is directed toward the Sun. The vehicle coordinates have a fixed orientation in space



(a) Orbit and planet.

(b) Spinning vehicle.

(c) Planet-oriented vehicle.

(d) Sun-oriented vehicle.

Figure 4. - Planet coordinate systems for spinning and oriented vehicles.

(assuming the planet to be stationary with respect to the Sun, which is essentially true during the time it takes to complete several orbits).

Celestial Coordinates

To determine the contribution of the Sun to spacecraft heating, the celestial location of the vehicle with respect to the celestial coordinates X_c, Y_c, and Z_c must be specified, but first, two astronomical terms, ecliptic and vernal equinox, will be introduced.

Positions in the solar system are commonly defined with respect to the ecliptic and the vernal equinox. The ecliptic is the plane described by Earth as it orbits the Sun. The vernal equinox, symbolized by Υ, is a fixed line from the Earth, directed

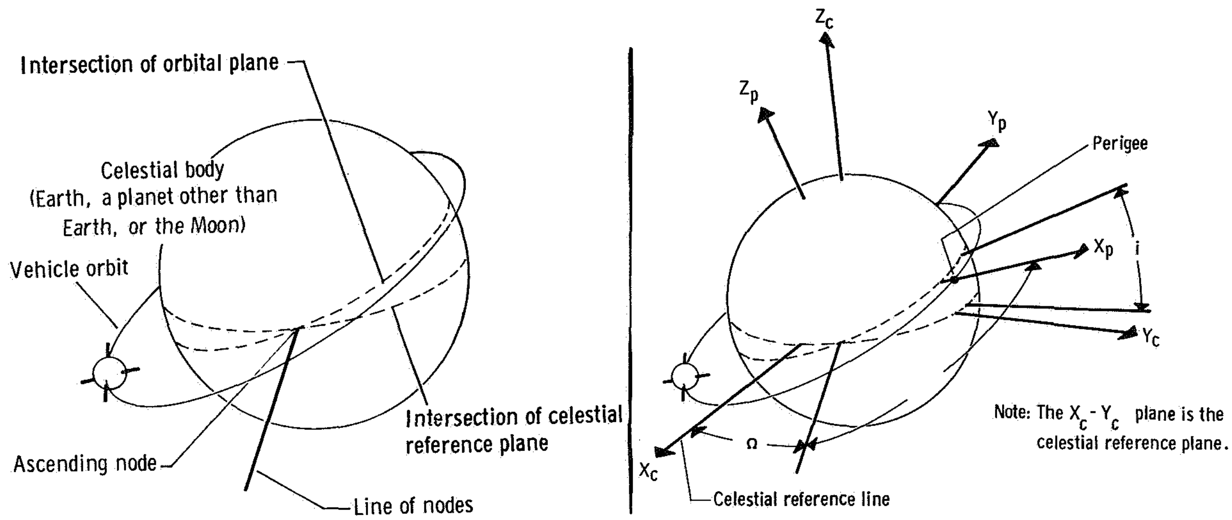
toward the Sun at the instant the Sun crosses the Earth equator from south to north in its apparent annual motion along the ecliptic. The direction of the vernal equinox varies slightly (approximately 50.27 seconds of arc per year). Hence, to specify the coordinates of an object, it is necessary to state which vernal equinox is referred to as the principal direction (for example, the equinox of 1950 or 1965).

Thus, the Earth intersects the vernal equinox at the start of spring (in the Northern Hemisphere). The vernal equinox also lies along the line of nodes described by the intersection of the Earth equatorial plane with the ecliptic. The other point at which the Sun crosses the Earth equator, going from the Northern to the Southern Hemisphere, is designated by the symbol $\underline{\Omega}$ and is the beginning of autumn in the Northern Hemisphere (autumnal equinox). At both points, day and night are equal.

The orbit of a vehicle about Earth, a planet other than Earth, or the Moon is conventionally related to the celestial X_c-, Y_c-, and Z_c-axes of the planet by three angles Ω, ω, and i. Before these functions can be defined, it is necessary to identify the geometric relationship between the vehicle orbit and the celestial axes. In figure 5(a), the general orbit of a vehicle is shown, with the intersection of the orbital plane and the planet surface shown in a broken line. The other broken line represents the intersection of the plane containing the celestial X_c- and Y_c-axes with the planet surface. The broken lines cross at two points. (Only one point is visible in fig. 5(a).) The two points define the line of intersection of the orbital plane and the plane containing the X_c- and Y_c-axes. The two intersections are commonly referred to as the ascending node and the descending node, and the line connecting the nodes is called the line of nodes. The vehicle is at the ascending node when it is passing upward (north) through the X_c-Y_c plane.

The orbit and the X_c-, Y_c-, and Z_c-axes are related by Ω, ω, and i, as shown in figure 5(b). The angle Ω is the longitude of the ascending node, measured counterclockwise in the X_c-Y_c plane from X_c to the line of nodes. The angle ω is the argument of perifocus, measured in the orbital plane in the direction of travel from the ascending node to the perigee. The angle i represents the true inclination between the X_c-Y_c plane and the orbital plane. The axes of the orbital plane are represented by X_p, Y_p, and Z_p, where X_p is directed through the perigee of the orbit, as previously defined.

Any number of reference X_c-, Y_c-, and Z_c-axes can be chosen. The primary consideration in choosing celestial coordinate systems for the analysis in this report was that the systems should be compatible with standard astronomical references in order to minimize input data compilation time and effort by the program user. The geocentric, modified heliocentric, and selenographic systems were selected to describe orbits about Earth, a planet other than Earth, and the Moon, respectively.

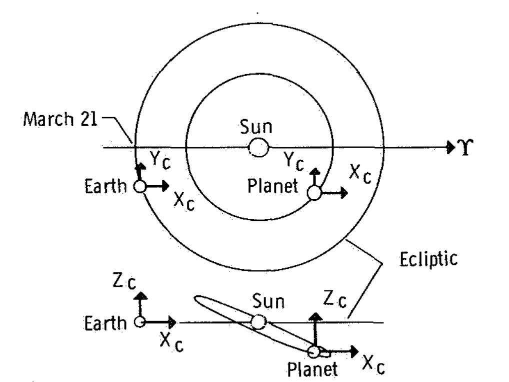


(a) General relationship of vehicle and celestial body.

(b) General relationship of planet and celestial coordinate systems.

Figure 5. - Relationship between orbit and general celestial coordinate systems.

Conventional geocentric coordinates are employed to define orbits about Earth. In this system, the X_c-Y_c reference plane is the plane of the Earth equator, with the X_c-axis directed along the vernal equinox, as shown in figure 6.



Note: Earth X_c- and Y_c-axes lie in the Earth equatorial plane.
Planet X_c- and Y_c-axes are parallel to the ecliptic.

Figure 6. - Celestial coordinate system for Earth (geocentric) and other planets (modified heliocentric).

A modified heliocentric coordinate system is used to define orbits about planets other than Earth. Since the equatorial planes of all planets are not well defined, the X_c-Y_c reference plane has been chosen parallel to the ecliptic, with the X_c-axis directed parallel to the vernal equinox. The X_c-, Y_c-, and Z_c-axes for planets are also illustrated in figure 6.

Conventional selenographic coordinates are employed to define orbits about the Moon. In this system, the X_c-Y_c reference plane is the plane of the Moon equator, and the Z_c-axis extends through the north pole of the Moon (fig. 7). The positive direction of the X_c-axis is from the center of the Moon out through the prime meridian of the Moon. By definition, the prime meridian

of the Moon passes through the mean center of the Moon. The mean center is the point on the lunar surface that is directed toward the center of the Earth when the Moon is at the mean ascending node, and the node coincides with the mean perigee or mean apogee. The longitude is measured as positive toward the west, as seen by an observer on Earth, or in a counterclockwise direction from the X_c-axis (toward Mare Crisium). The direction of the X_c-axis in space is not fixed, but revolves with the Moon, making one turn every 28 days.

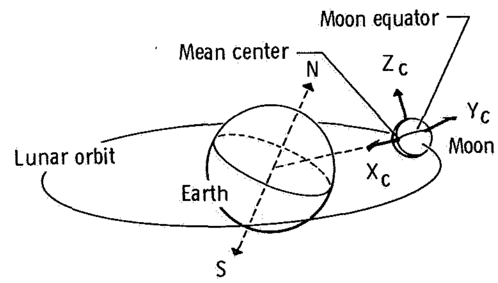


Figure 7. - Celestial coordinate system for the Moon (selenographic).

Position of the Sun

The location of the Sun with respect to the planet being orbited must be specified to complete the definition of Sun, planet, and vehicle relationships. The position of the Sun can be expressed with respect to the celestial body being orbited (in X_c, Y_c, and Z_c coordinates) in terms of right ascension RA and declination DEC, as shown in figure 8. For Earth, RA and DEC can be obtained directly from an ephemeris (ref. 1) for each day of the year. For the Moon, the required coordinates are listed in the ephemeris as latitude and colongitude, where colongitude is

$$\text{colongitude} = 90^\circ - \text{longitude}$$

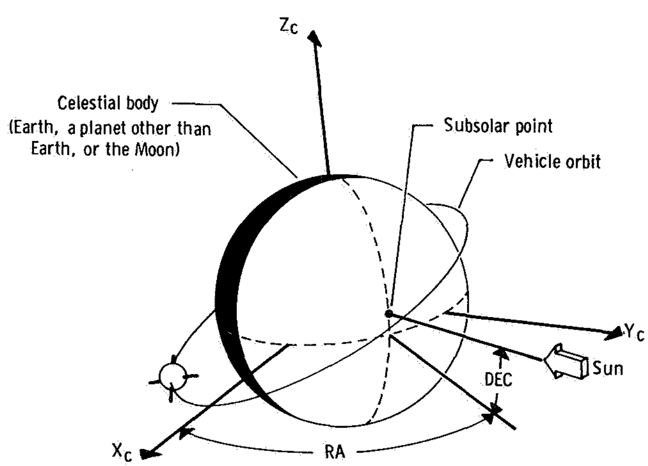


Figure 8.- Position of the Sun relative to the celestial coordinate system.

Longitude must always be positive. Therefore, if colongitude is greater than 90°, the equality becomes colongitude = 450° - longitude.

For a planet other than Earth, the right ascension and declination of the planet with respect to the Sun are given in heliocentric coordinates in reference 1. The position of the Sun with respect to the modified heliocentric coordinate system can be obtained from these data, as demonstrated in the following examples. If the declination of the planet with respect to the Sun is +10°, the declination of the Sun with respect to the planet is -10°. If the right ascension or longitude of the Sun with respect to the planet is 236°, the required value is 56° (236° + 180° = 416°; 416° - 360° = 56°).

The position of the Sun can be expressed with respect to the planet coordinate X_p-, Y_p-, and Z_p-axes in terms of α, β, and γ as shown in figure 9. The coordinates RA and DEC can be transformed into α, β, and γ by performing rotations through the angles Ω, ω, and i, as shown in figures 8 and 9. In the first transformation, the X_c-axis is rotated about the Z_c-axis through an angle Ω into the line of nodes (fig. 5). In the second transformation, the Y_c-axis is rotated about the X_c-axis through the angle i. Finally, the X_c-axis is rotated through an angle ω about the Z_c-axis.

Performing the two transformations gives the following relationships:

$$
\begin{aligned}
\cos \alpha = {} & [(\cos \omega)(\cos \Omega) - (\sin \omega)(\sin \Omega)(\cos i)] (\cos RA)(\cos DEC) \\
& + [(\cos \omega)(\sin \Omega) + (\sin \omega)(\cos \Omega)(\cos i)] (\sin RA)(\cos DEC) \\
& + (\sin \omega)(\sin i)(\sin DEC)
\end{aligned}
\tag{25}
$$

$$
\begin{aligned}
\cos \gamma = {} & [(-\sin \omega)(\cos \Omega) - (\cos \omega)(\sin \Omega)(\cos i)] (\cos RA)(\cos DEC) \\
& + [(-\sin \Omega)(\sin \omega) + (\cos \Omega)(\cos \omega)(\cos i)] (\sin RA)(\cos DEC) \\
& + (\cos \omega)(\sin i)(\sin DEC)
\end{aligned}
\tag{26}
$$

$$
\begin{aligned}
\cos \beta = {} & (\sin \Omega)(\sin i)(\cos RA)(\cos DEC) \\
& + (-\cos \Omega)(\sin i)(\sin RA)(\cos DEC) + (\cos i)(\sin DEC)
\end{aligned}
\tag{27}
$$

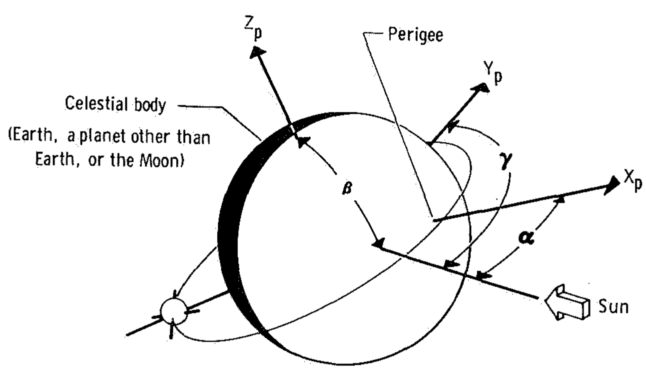


Figure 9. - Position of the Sun relative to the planet coordinate system.

For convenience, the derivations of equations (25) to (27) have been omitted.

After the position of the Sun with respect to the planet and the orbital plane has been obtained, the final step is to determine the position of the Sun with respect to the orbiting spacecraft. In the following paragraphs, the position of the Sun is determined with respect to spinning, planet-oriented, and Sun-oriented vehicles.

Position of the Sun with respect to spinning vehicles. - Some of the solar energy that strikes the planet and the atmosphere of the planet is scattered back into space and impinges on the orbiting vehicle. This radiation (albedo) travels

through the angle θ_s (fig. 2). The sum of the direction cosines of the planet-vehicle line times the sum of the direction cosines of the Sun-planet line is equal to $\cos\theta_s$, which reduces to

$$\cos\theta_s = \frac{X_p}{D}\cos\alpha + \frac{Y_p}{D}\cos\gamma \tag{28}$$

Solar energy directly irradiating the vehicle is the same throughout the orbit (except when the vehicle is shaded by the planet) if the assumption is made that the period of rotation of the spinning sphere is short (that is, that all surface elements continuously receive radiation from the Sun), and if the assumption is made that the Sun is a point source infinitely far away. Therefore, no other angles relating the position of the Sun with respect to the vehicle are required.

Position of the Sun with respect to planet-oriented vehicles. - The relative positions of the Sun, vehicle, vehicle element, and planet are defined by the angles Ω_s, Λ_s, δ (fig. 10), and θ_s (fig. 2). The function $\cos\theta_s$ for a planet-oriented vehicle is the same as $\cos\theta_s$ for a spinning vehicle and is given in equation (28).

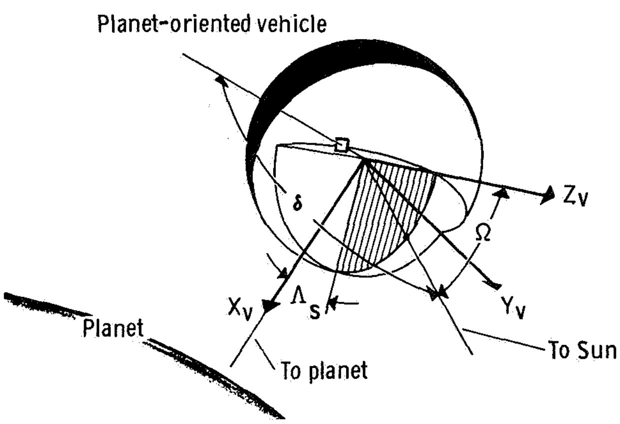


Figure 10. - Position of the Sun relative to the vehicle coordinate system (planet oriented).

Since Z_v is parallel to Z_p and since it is assumed that the Sun is a point source infinitely far away, it follows that

$$\Omega_s = \beta \tag{29}$$

It can also be shown that

$$\Lambda_s = \Sigma - \emptyset + \pi \tag{30}$$

where Σ is the true anomaly of the solar projection of the X_p-Y_p plane (fig. 4d). If Λ_s is negative, 2π radians must be added to Λ_s. However, only $\sin \Lambda_s$ and $\cos \Lambda_s$ are required by the analysis in this report; therefore, equation (30) need not be modified for negative values.

The angle δ between the element-vehicle line and the Sun-vehicle line is derived by adding the products of the corresponding direction cosines of the two lines, which gives

$$\cos \delta = \sin \Omega' \cos \Lambda' \sin \Omega_s \cos \Lambda_s + \sin \Omega' \sin \Lambda_s \sin \Omega_s \sin \Lambda_s + \cos \Omega' \cos \Omega_s \tag{31}$$

Position of the Sun with respect to Sun-oriented vehicles. - The angle θ_s is independent of vehicle orientation; therefore, $\cos \theta_s$ for a Sun-oriented vehicle is the same as $\cos \theta_s$ for a spinning vehicle, which is given in equation (28).

By definition, the X_v-axis is directed toward the Sun; therefore

$$\Omega_s = \frac{\pi}{2} \tag{32}$$

and

$$\Lambda_s = 0 \tag{33}$$

as shown in figure 11.

The angle δ between the element-vehicle line and the Sun-vehicle line can be derived by combining equations (31), (32), and (33) to obtain

$$\cos \delta = \sin \Omega_s \cos \Lambda_s \tag{34}$$

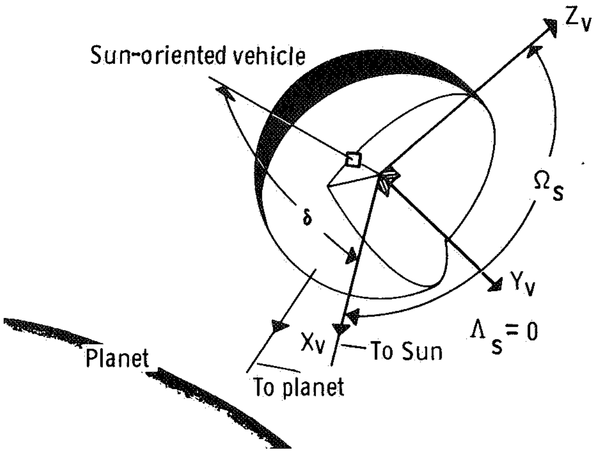


Figure 11. - Position of the Sun relative to the vehicle coordinate system (Sun oriented).

NUMERICAL ANALYSIS

It is important that numerical techniques be both accurate and fast. The accuracy and speed of numerically integrating an equation such as the general thermal expression given in equation (19) are related to the specific method and step-size to be used and to the complexity of the function. Of course, accuracy also depends on proper application of the numerical technique employed.

Method of Integration

Multistep methods require a constant step-size. Although they are generally faster than single-step methods, their use for this specific problem would necessitate a time-consuming iterative solution of equation (18) to find the true-anomaly increment corresponding to the constant-time increment. Consequently, a single-step integration method is chosen.

An analysis of single-step methods in relation to the general equation to be solved resulted in the selection of the fourth-order Runge-Kutta technique. This method has long been accepted as being the most accurate and the fastest method. The Runge-Kutta technique is well suited as a rapid method for use in equation (19), since C_1 and C_2 need to be calculated only once during each time interval. In the solution of equation (19), the integration speed of the fourth-order Runge-Kutta method is very close to the integration speed of a lower ordered method, or even to the integration speed of the multistep methods that are normally much faster.

Step-Size and Error Analysis

Assuming that the error attributable to a given single-step method is less than the maximum tolerable error, optimization of operating speed can be achieved by investigating the question of maximum step-size.

The computer program has been written so that a step-size $\Delta\phi$ can be input to the computer. The program prints out every $n\Delta\phi$ interval, where n is a specified integer; however, calculations may be based on a smaller, more practical interval for accuracy, speed, and stability. The practicality of $\Delta\phi$ is determined at the start of each interval. Practical step-size and its determination by the program are described in appendix C.

The errors induced by numerical integration can be broken down in the following manner.

$$E_n = e_{t,n} + e_{t,a} + e_{ro} \tag{35}$$

where E_n = total error at $t = n$

$e_{t,n}$ = one-step truncation error (the error caused by approximation over step n)

$e_{t,a}$ = accumulated truncation error over steps 1 to n - 1

e_{ro} = accumulated effect of round-off error over n steps

Accumulated errors. - Contrary to the usual case in numerical analysis, the sum of the accumulated errors $e_{t,a}$ and e_{ro} is bounded by some number B, which is much less than the accuracy of the input data for any practical step-size and is therefore negligible regardless of total integration time. The boundary is a result of the stability of the function to be integrated; that is, the solution converges to a specific temperature at a given true anomaly and, on all subsequent orbits, will be virtually at that temperature. Since the temperature at point n in one orbit is the same as the temperature at point n in the next orbit, there is no significant accumulation of errors.

To test this error analysis, a spinning-satellite case was programed for the IBM 1620 computer so that $e_{t,a}$ and e_{ro} could be analyzed separately. To show that e_{ro} was nearly zero, the program was run using eight-digit and then 12-digit accuracy. The difference in the two solutions occurred in the seventh or eighth decimal place in all the orbits run.

The analysis included the calculation of a function proven to be asymptotic to the accumulated truncation error of the integration (ref. 2). Although the solution of this function was small with respect to the solution of the thermal equation and was oscillatory in nature, it did increase gradually in magnitude. Nevertheless, the stability of the function was generally verified, since asymptotic approximations are not exact.

One-step truncation error. - To study $e_{t,n}$, the IBM 1620 computer analysis for total truncation error was used again. Since the one-step error $e_{t,1}$ made during the first step is generated by the accumulated error function, the analysis necessarily contained the rudiments of a one-step error function. The only modification necessary to generate the one-step errors continuously was to make the computer "think" that each step was the first. This technique was applied to the integration of many differential equations with closed-form solutions and was found to have good accuracy. Although the level of effort did not permit extensive application of this technique to equation (19), the runs that were made indicated that any practical step-size gave an $e_{t,n}$ of less than 0.05° R.

Since the sum of the accumulated errors is bounded by B, equation (35) can be written as

$$E_n = e_{t,n} + B \tag{36}$$

The results of the error analysis indicate that $e_{t,n} < 0.05^\circ$ R and that $B < 0.1^\circ$ R; therefore, the total error attributable to the numerical integration is

$$E_n < 0.15^\circ \text{ R} \tag{37}$$

which is negligible, considering the accuracy of the input data.

Integration Technique When the Function Is Nondifferentiable

A major contribution of the numerical analysis was the discovery and elimination of a significant error caused by misapplication of the integration techniques employed in previous similar studies. In all standard numerical techniques, the function to be integrated is assumed to be continuously differentiable at every point in the integration interval. This assumption does not apply to equation (19) because of the behavior of the constant C_1. When the orbiting vehicle enters or leaves the shadow of the planet, C_1 may change suddenly from a relatively large number to almost zero, or vice versa, causing the function to be nondifferentiable at the Sun-shade points. In the IBM 1620 computer analysis, the single-step error in an interval containing a Sun-shade point was revealed to be much larger (up to 10° R larger) than the total accumulated error encountered immediately prior to that interval. In support of the stability conjecture, even this large error became negligible after a few integration steps.

The error from misapplication is eliminated by subdividing each interval containing a Sun-shade point so that the nondifferentiable point coincides with the boundary of the interval and thus does not exist within the interval.

DIGITAL COMPUTER PROGRAM

The determination of impinging heat loads, absorbed heat loads, and transient temperatures for up to 200 surface elements of a spacecraft in orbit is an ideal application of a high-speed digital computer. Performing this determination in any other manner would be impractical, at best. Accordingly, a Univac 1108 computer program incorporating the theory and numerical techniques described in the previous sections has been written and validated. Programing was done in FORTRAN V to facilitate any modifications that the program user might wish to perform. Appendixes D to J provide the program user with detailed information on the computer program source and data deck structure.

Summary of Computer Program Capabilities and Applications

The computer program is designed to compute, plot, and print out heat loads and temperatures for a vehicle in orbit about the Moon or about any planet except Pluto. The orbiting vehicle may be spinning or have a fixed orientation with respect to either the Sun or the celestial body orbited. The planet surface temperature, which is used in determining the amount of impinging thermal radiation originating from the planet, is assumed to be constant for all celestial bodies except for the Moon, for which surface temperature may be considered either constant or variable.

The heat loads during one orbit or any fraction of an orbit can be determined by the computer program. When it is necessary to compute temperature, more than one orbit may be specified. However, if all of the temperatures become stable (that is, differ by less than 0.5° R from one orbit to the next), the case being computed is automatically terminated.

The optical properties, specific heat, and density of the vehicle coating(s) and substrate(s) are temperature dependent. Up to 21 data points of material property versus temperature from 0° to 10 000° R (the effective temperature of the Sun) may be specified. Absorptance with respect to heat flux radiated by the planet is found as a function of the effective temperature of that part of the planet actually radiating to the element of an orbiting vehicle. A maximum of eight tables of optical properties may be used. Eight tables of specific heat and of density corresponding to eight possible substrate materials for vehicle skin may also be used.

When temperature calculations are desired, up to eight schedules of internal heat versus time can be used. Each data set is input as a table of internal heat and switching time, corresponding to a change to the next value of internal heat. As many as 20 different values (10 duty cycles) may be included in each of the eight tables. If the program runs for more than one orbit, the same sequence of internal heat loads is applied for the successive orbits.

Satellite position in orbit is given by the true anomaly $\emptyset$ measured from perigee. A starting value $\emptyset_o$ and a step-size $\Delta\emptyset$ are input. The starting value $\emptyset_o$ must be between 0° and 360°, and $\Delta\emptyset$ must be a submultiple of 360° and must be $\geq 2°$. For example, 2°, 5°, 6°, 7.5°, 8°, 9°, or 10° are all acceptable values for $\Delta\emptyset$, but 7° is not acceptable, since 360/7 is not an integer.

The step-size $\Delta\emptyset$ may be subdivided internally to give the optimum interval with respect to accuracy and computer time; however, the input value of $\Delta\emptyset$ will not be exceeded. For temperature calculations, external heat fluxes are considered constant throughout the specified $\Delta\emptyset$ interval, provided the vehicle does not pass in or out of the shadow of the planet during the time corresponding to $\Delta\emptyset$. Furthermore, only one change in internal heat for each element is recognized per interval. Experience indicates that $\Delta\emptyset = 10°$ is a reasonable upper bound.

The position of the Sun relative to the orbit may be given conventionally as right ascension and declination, both of which can be obtained from an ephemeris; or the position of the Sun may be specified in terms of the angles α, γ, and β relative to the X_p, Y_p, and Z_p coordinate axes.

As many as 200 elements of oriented vehicles may be processed in a single case. Each element has a specified thickness, initial temperature, and position on the vehicle. An element may use one of eight choices for each of the following: optical properties, substrate material, and internal heat duty cycle.

The effects of variations of thickness, initial temperature, material, or internal heat loads can be studied in a single case if a number of elements are chosen with the same positions, but with different values for the other parameters. Thus, a single case may be an entire parametric study in itself. Additional flexibility is provided so that the unchanged values can be represented by blank fields in the input deck if any of the input parameters are to remain the same from one case to another.

General Deck Preparation

Figure 12 is an illustration of the physical sequence of the deck structure required. The name shown on the card preceding each routine (i.e., DECK1) can be related to the actual name of the routine by the following list:

EXEC = PILØT
DECK1 = HEAD
DECK2 = TINPUT
DECK3 = LØØP
DECK4 = TØUT
DECK5 = HEAT
DECK6 = FREAD
DECK7 = QIFIND
DECK8 = TALLY
DECK9 = LØCUS
DECK10 = TEMPER
DECK11 = INIT
DECK12 = FIND
DECK13 = SUNØR
DECK14 = BETA90
DECK15 = WYE
DECK16 = SIGBET
DECK17 = INTERP
DECK18 = ARRØUT
DECK19 = ARCØS
DECK20 = QUART
DECK21 = PHIFN
DECK22 = GFN
DECK23 = FØFXY
DECK24 = DELTA
DECK25 = ERRØR
DECK26 = GEØFAC
DECK27 = QIIN
DECK28 = DDVETA
DECK29 = DDFERI
DECK30 = TABLE
DECK31 = MAIN2
DECK32 = DRAW
DECK33 = SKALE
DECK34 = XINTRP
DECK35 = ACCEND
DECK36 = HILØW
DECK37 = TIDENT
DECK38 = FDTA

If Stromberg-Carlson 4020 (SC-4020) plots are not requested, LINK2 may be omitted entirely. This can be done by deleting card number DK033000 of subroutine LØØP (DECK3) and by removing all subroutines which make up LINK2 (DECK31 through DECK38). This procedure must be used if data-computation facilities do not have SC-4020 capabilities described in appendix H.

Data Deck Preparation

The data deck consists of three groups of data. They are the permanent-data cards, the material-properties cards, and the case-data cards. The permanent data consist of 147 permanent-data cards that include 144 cards containing the radiation configuration factors and three cards containing alphabetic data used in headings. For documentation purposes, the permanent-data cards are listed as part of the sample-case input data discussed in appendix G. Since the permanent data must be used exactly as listed, only the material-properties data and case data shall be of concern for data preparation.

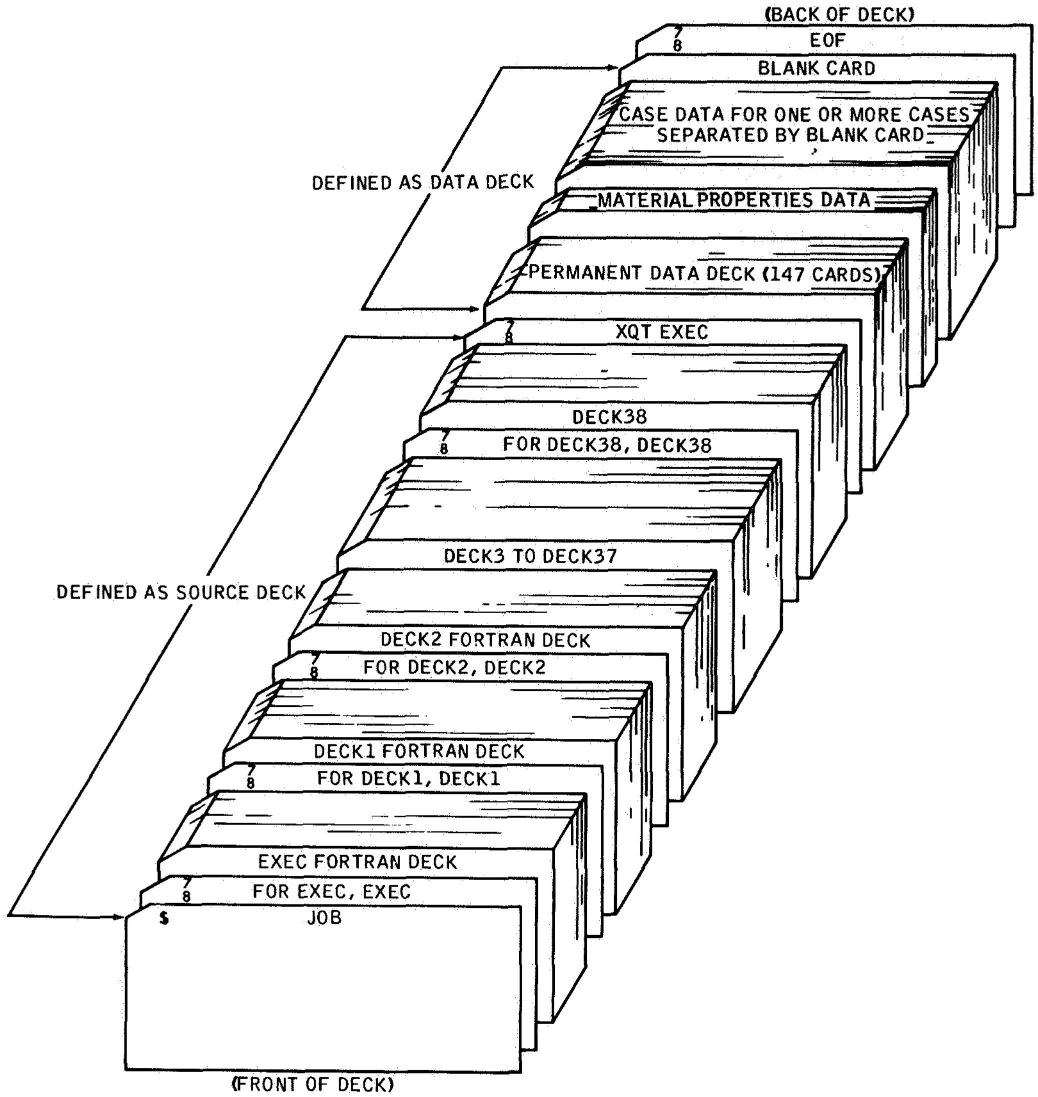


Figure 12. - Deck structure.

Appendix I is a guide for preparing program data. The guide is complete enough that the program user can use the appendix to prepare data decks. Additional information and the related theory are described in other sections of the report and in the other appendixes.

COMPUTER PROGRAM APPLICATION

A hypothetical lunar mission was run, using the described computer program. For the hypothetical lunar-orbital mission, the spacecraft was planet oriented, and a variable planet surface temperature was used. The orbit parameters were such that

pericynthion occurred over the intended landing site, which was 13° south of the Moon equator and 3° east (as seen from Earth) of the prime meridian of the Moon. A detailed discussion of the use of the computer program in spacecraft design and orbit selection is presented in reference 3.

Pertinent orbit data consisted of the following:

Altitude H, n. mi.	10 to 190
Inclination i, deg	13
Right ascension of ascending node Ω, deg	87
Argument of perifocus ω, deg	270
True anomaly at initial time ϕ_o, deg	0

The mission was flown on December 1, 1963. The position of the Sun in selenographic coordinates, as given by an ephemeris, was as follows:

Colongitude, deg	88.74
Declination DEC, deg	0.86
Right ascension (90° - colongitude) RA, deg . . .	1.26

At a declination of 0.86° and a right ascension of 1.26°, the Sun is almost in the orbital plane.

The temperature-time history of differently oriented and differently painted surface elements reveals several interesting characteristics. In figure 13, it is shown that a white element facing away from the Moon cools initially, even though it may be facing almost directly into the Sun. However, a similarly oriented black element rises to a peak temperature at $\phi = 60°$, then gradually drops in temperature as it turns away from the Sun. This difference is to be expected, since the white element reflects a considerable amount of solar energy; whereas, the black element will absorb most of the solar radiation that impinges upon its surface.

In figure 14, it is shown that the temperature curves of a black element and a white element facing the Moon are similar, since black and white elements absorb long-wavelength radiation in almost the same amount. Also, the hump in the black-element curve at about $\phi = 100°$ and $\phi = 260°$ occurs because both elements are briefly irradiated by the Sun immediately before entering the shadow of the Moon and immediately after leaving the shadow. However, the hump appears in the black-element curve only, since the black element absorbs the solar radiation more readily.

In figure 15, comparison of the black element facing the Moon with the black element facing away from the Moon and toward the Sun reveals that at $\phi = 0°$, the element facing the Moon is almost as hot as the element facing away from the Moon and toward the Sun. The conclusion is that, at low lunar orbits, planet heat can be as significant as solar heat.

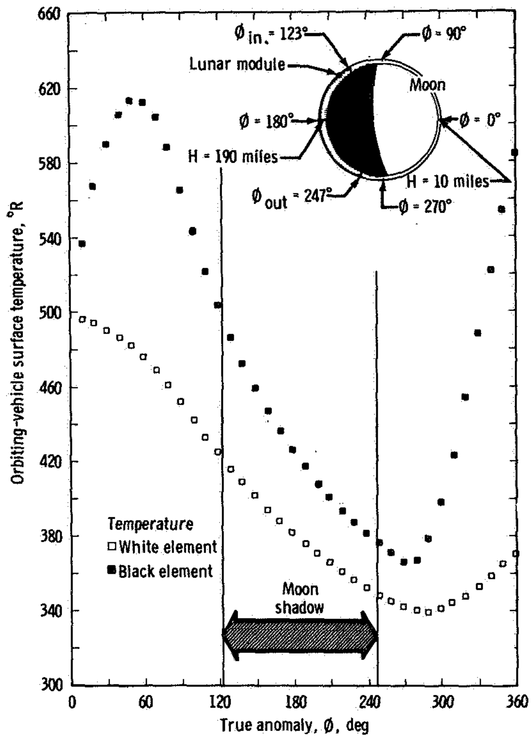


Figure 13. - Simulated lunar module, elements facing away from the Moon.

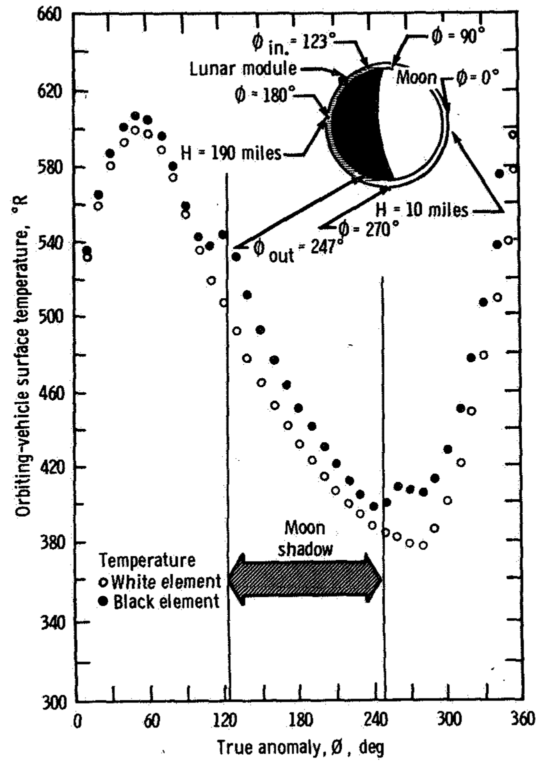


Figure 14. - Simulated lunar module, elements facing the Moon.

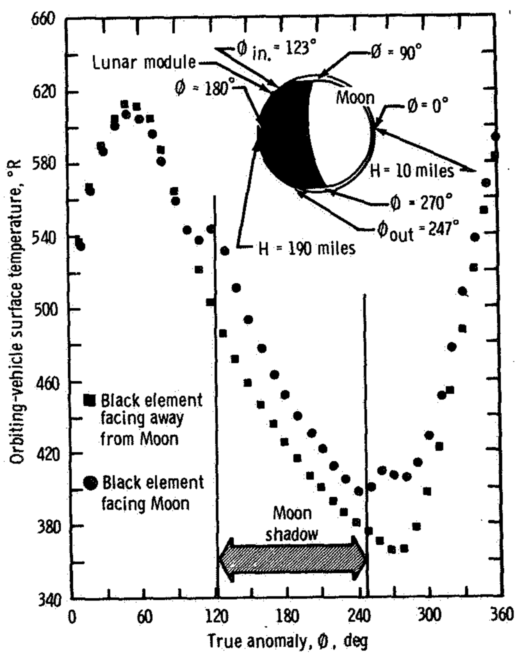


Figure 15. - Simulated lunar module.

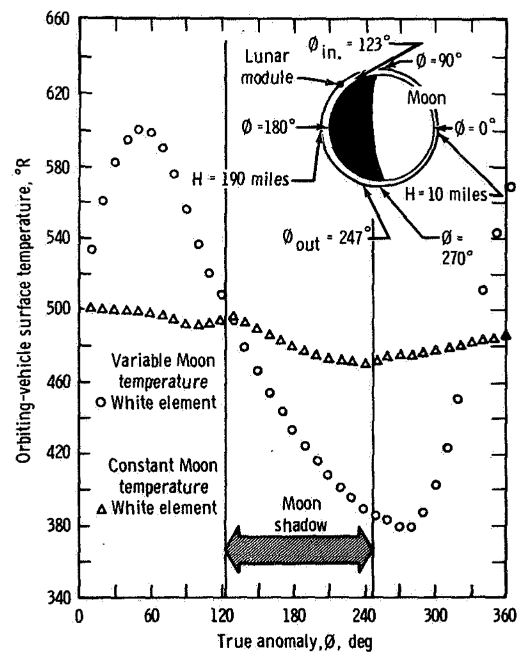


Figure 16. - Comparison of constant and variable Moon temperature.

To investigate the effect of the surface temperature gradients of the Moon not being considered, the same case was run, assuming a constant Moon temperature. The results plotted in figure 16 reveal that the constant-Moon-temperature curve is a flat curve that averages out the maximum and minimum peaks of the variable-Moon-temperature curve. It is clearly shown in figure 16 that a significant variation (about 100° R) is caused by neglecting the surface temperature gradient of the Moon. These results confirm the importance of the variable-planet-temperature method in analyzing lunar missions.

CONCLUDING REMARKS

An operational computer program to predict spacecraft heat loads and temperatures has been developed. The program is applicable to a wide variety of vehicle-mission combinations. Although no unduly restricted assumptions are incorporated into the celestial, thermal, and numerical theory, certain conditions were not considered in order to retain the desired versatility. However, the program was written so that it could be expanded readily to include additional features and details.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, August 22, 1968
039-00-00-85-72

APPENDIX A

INTERSECTION OF ORBIT AND SHADOW

The intersection of the orbit and the shadow can be determined by simultaneously solving the equations that express the vehicle path and the trace of the shadow on the orbital plane.

If $\beta = 0^\circ$ or $\beta = 180^\circ$, the trace of the shadow is a circle of radius r_p that does not intersect the vehicle orbit. (The angle β is illustrated in appendix B.) If $0^\circ < \beta < 180^\circ$, but $\beta \neq 90^\circ$, the trace is a semiellipse, as shown in figure A-1. The equation of the orbit path, based on the notation shown, is

$$\frac{\left(X_p + c\right)^2}{a^2} + \frac{Y_p^2}{b^2} = 1 \tag{A1}$$

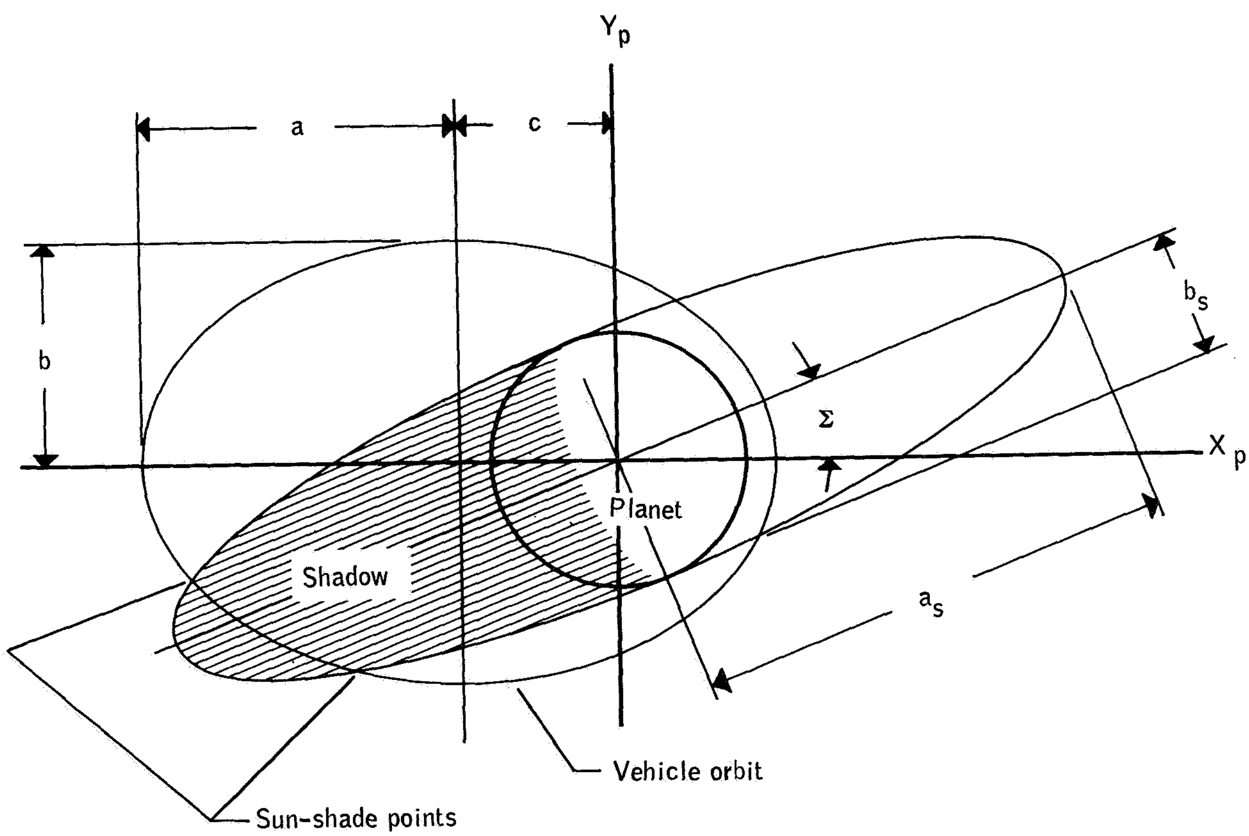


Figure A-1. - Intersection of the orbit plane and the shadow of the planet.

The corresponding expression for the intersection of the shadow with the orbital plane is

$$\frac{\left(X_p \cos \Sigma + Y_p \sin \Sigma\right)^2}{a_s^2} + \frac{\left(X_p \sin \Sigma - Y_p \cos \Sigma\right)^2}{b_s^2} = 1 \tag{A2}$$

Equations (A1) and (A2) can be combined to yield a biquadratic (quartic), which is solved in this analysis by the Ferrari method. Other numerical approaches may be faster, but they become unstable in some cases. The Ferrari method, which can be used to solve any quartic equation, is explained in most theory-of-equation texts and in many mathematical handbooks (for example, ref. 4).

After the quartic equation has been solved for X_p, the corresponding Y_p values can be determined from either equation (A1) or (A2); however, care must be taken to avoid accepting an extraneous root. Extraneous roots do not occur if both equations are solved for Y_p^2 and the expressions equated. The result reduces to the following equation, which is single valued for all X_p.

$$\frac{Y_p}{a} = \chi\left[(\cos \beta \cos \Sigma)^2 + \sin^2 \Sigma\right] - \left(\frac{b_s}{a}\right)^2$$
$$+ \left(\frac{b}{a}\right)^2 \left[\left(1 - \chi + \frac{c}{a}\right)^2\right] \left[(\cos \beta \sin \Sigma)^2 + \cos^2 \Sigma\right] \tag{A3}$$

where

$$\chi = \frac{X_p}{a} \tag{A4}$$

The true anomaly of the Sun-shade points is calculated from

$$\tan \phi = \frac{Y_p}{X_p} \tag{A5}$$

If the shadow and orbit ellipses do not intersect or if they cross in only two places, the quartic equation can yield spurious (that is, false) real roots. Since equation (A3) is valid only at the ellipse intersections, solutions of equation (A3) that correspond to spurious roots are meaningless. Therefore, the validity of each pair of coordinates must be determined, and this is accomplished by testing whether the X_p and Y_p values satisfy both equations (A1) and (A2).

If $\beta = 90°$, the trace of the shadow ellipse degenerates to a pair of parallel lines that are expressed in polar form as

$$r_s \sin(\Sigma - \phi) = r_p \tag{A6a}$$

and

$$r_s \sin(\Sigma - \phi) = -r_p \tag{A6b}$$

where r_s is the distance from the lines to the center of mass of the planet. A similar expression of the orbit ellipse is

$$r_o = \frac{b^2}{a + c \cos \phi} \tag{A7}$$

where r_o is the distance from the orbit ellipse to the center of mass of the planet.

Equating r_s and r_o in equations (A6a) and (A7) gives

$$\left(b^2 \sin \Sigma + cr_p\right) \cos \phi - b^2 \cos \Sigma \sin \phi - ar_p = 0 \tag{A8a}$$

In general, equation (A8a) is transformed to a quadratic in $\cos \phi$ by substituting $\pm\left(1 - \cos^2\phi\right)^{1/2}$ for $\sin \phi$. The roots of this quadratic are substituted into equation (A8a) to give $\sin \phi$. Once $\sin \phi$ and $\cos \phi$ are known, ϕ is easily found. A similar procedure yields the other Sun-shade point if equations (A6b) and (A7) are equated.

$$\left(b^2 \sin \Sigma + cr_p\right) \cos \phi - b^2 \cos \Sigma \sin \phi + ar_p = 0 \tag{A8b}$$

If the coefficient of $\sin \phi$ or $\cos \phi$ in equation (A8b) vanishes, the problem is less difficult, in that $\sin \phi$ or $\cos \phi$ can be solved for directly, and the corresponding function is determined from either $\sin \phi = \pm\left(1 - \cos^2\phi\right)^{1/2}$ or $\cos \phi = \pm\left(1 - \sin^2\phi\right)^{1/2}$.

Equations (A5) and (A8b) may give zero, two, or four valid mathematical roots; however, two of the roots may not satisfy the condition that the Sun-shade points lie on the shaded side of the orbit. A root is discarded unless the angle between the line connecting the Sun-shade point and the planet and the line of the projection of the Sun on the orbital plane is obtuse.

APPENDIX B

RADIATION HEAT-TRANSFER DERIVATIONS

A general expression for thermal radiation from one surface to another can be derived by considering the total radiation from the emitting surface. This derivation may be visualized by placing a hemisphere over the emitting-surface element A_e, as shown in figure B-1. This hemisphere will intercept all of the heat emitted from A_e, and the radiation received by an element dA_r is given by the equation

$$dq = I\frac{\epsilon_e \cos \phi_e A_e \cos \phi_r}{\ell^2} dA_r \tag{B1}$$

where ϕ_r (not shown) is the angle between a normal to dA_r and a line from dA_r to A_e, and ϵ_e is the emittance of A_e. The proportionality factor I is shown as the intensity of radiation. Assuming that the emitting surface is diffuse, the intensity is independent of direction and is constant. The apparent or intercepted intensity is proportional to A_e, as seen from dA_r on the hemisphere. Thus

$$I(\phi_e) = I \cos \phi_e \tag{B2}$$

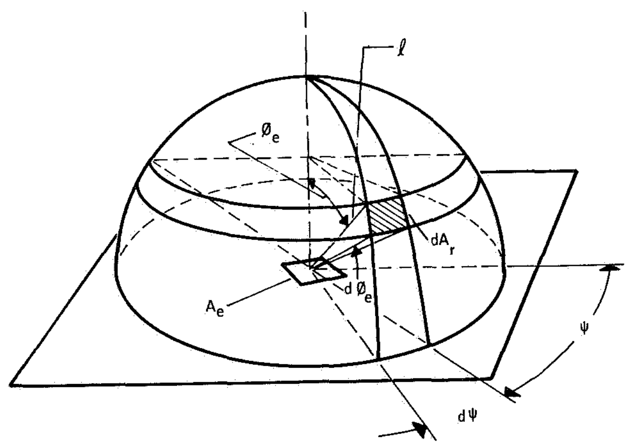


Figure B-1. - Mathematical model for deriving the general thermal-radiation equation.

which is Lambert's cosine law. If dA_r is on the hemisphere surface, ϕ_r is 0°; therefore

$$dq = \frac{I \cos \phi_e A_e \epsilon_e \, dA_r}{\ell^2} \tag{B3}$$

Writing dA_r in terms of ϕ_e and ψ and integrating, equation (B3) becomes

$$q = IA_e\epsilon_e\int_0^{2\pi} d\psi\int_0^{\pi/2} \cos \phi_e \sin \phi_e \, d\phi_e = IA_e\epsilon_e\pi \tag{B4}$$

The heat radiated by A_e is

$$q_{out} = \epsilon_e\left(\sigma T_e^{\,4}\right)A_e = \epsilon_e E_e A_e \tag{B5}$$

where E_e is the emissive power of A_e. Since all of the emitted heat is intercepted by the hemisphere, the heat emitted is equivalent to the heat received. Equating equations (B4) and (B5), simplifying the results, and solving yields

$$I = \frac{E_e}{\pi} \tag{B6}$$

Combining equations (B1) and (B6) and introducing the absorptance α_r of the receiving surface gives the general equation for radiant heat transfer between two surfaces

$$dq = \frac{E_e \cos \phi_e A_e \cos \phi_r \alpha_r \epsilon_e}{\pi \ell^2} dA_r \tag{B7}$$

In the following section of this appendix, equation (B7) will be used to derive specific equations that express the amount of planetary and albedo heat that is received, absorbed, or both, by either a spinning or an oriented vehicle. Derivations will be made for constant-temperature planets, as well as for variable-temperature planets.

Planet Heat Flux for a Spinning Vehicle and Constant Planet Temperature

Seavey (ref. 5) simplified the mathematics of the derivation with the theorem that the flux incident on a small surface element from an extended source of uniform brightness is independent of the shape of the element and the shape of the emitting surface. A modification of Seavey's solution is developed by first replacing the part of the planet that the vehicle receives radiation from with a concave disk of radius ℓ,

as shown in the top portion of figure B-2. This geometrical substitution can be visualized by observing that the Sun, a uniform emitting surface with respect to surface position, appears to the observer on Earth as a disk. Similarly, the vehicle is replaced by a flat disk that has an infinitesimal area, compared to the area of the planet disk.

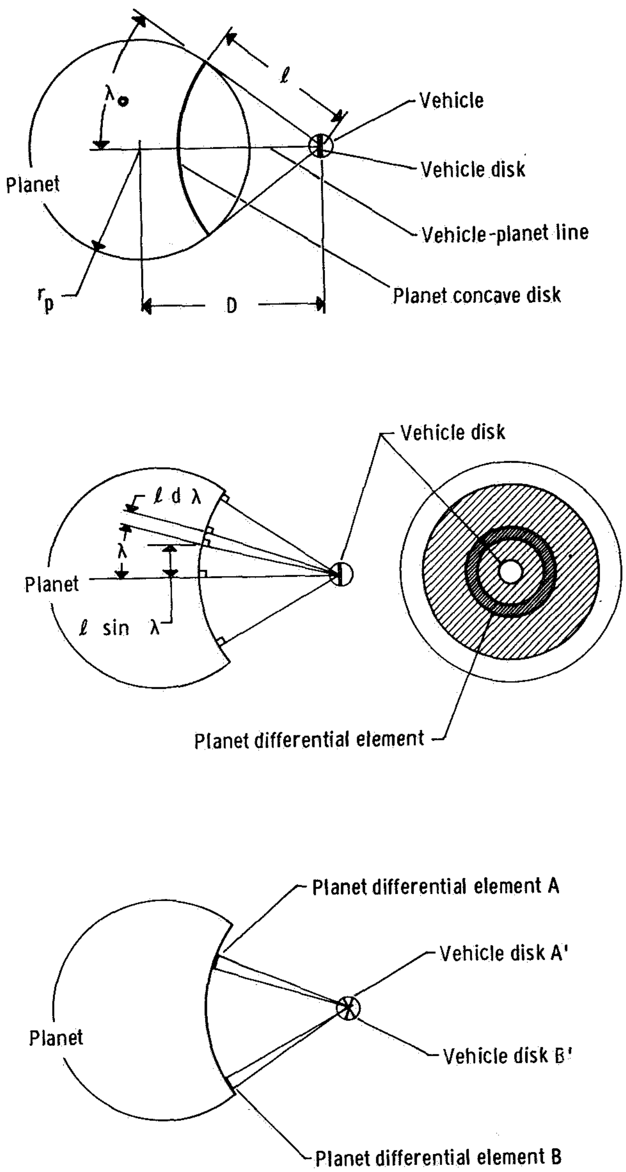


Figure B-2. - Seavey's model for determining radiation between two spheres of uniform brightness.

It can be seen in the center diagram of figure B-2 that every line between the vehicle and the planet intersects the planet concave disk perpendicularly. Likewise, the vehicle-planet lines can be made normal to the planet concave disk by letting the disk pivot about its center, allowing the planet differential elements to receive radiation from different orientations of the vehicle disk. Thus, in the bottom portion of figure B-2, element A receives radiation from element A', and element B receives radiation from element B'. The pivoting of the planet concave disk is justified by the previously mentioned theorem employed by Seavey.

Equation (B7) is modified to express the heat received by a vehicle area A_v from a ring-shaped element of area dA_p as

$$dq_p = \frac{E_p \cos \phi_p \cos \phi_v A_v \epsilon_p \alpha_p}{\pi \ell^2} dA_p \tag{B8}$$

Assuming that celestial bodies are perfect emitting surfaces (that is, that $\epsilon_p = 1$) and substituting $\phi_p = \phi_v = 0°$, equation (B8) is reduced to

$$dq_p = \frac{E_p A_v \alpha_p}{\pi \ell^2} dA_p \tag{B9}$$

The planet differential area and the effective vehicle area are

$$dA_p = [2\pi(\ell \sin \lambda)](\ell \, d\lambda) = 2\pi\ell^2 \sin \lambda \, d\lambda \tag{B10}$$

and

$$A_v = \pi r_v^2 \tag{B11}$$

The emissive power is

$$E_p = \sigma T_p^4 \tag{B12}$$

where T_p is the average planet temperature. A heat balance on the planet yields

$$T_p = \left[\frac{S(1 - R)}{4\sigma}\right]^{1/4} \tag{B13}$$

Combining equations (B12) and (B13) gives

$$E_p = \sigma\left\{\left[\frac{S(1 - R)}{4\sigma}\right]^{1/4}\right\}^4 \tag{B14}$$

which becomes

$$E_p = \frac{S(1 - R)}{4} \tag{B15}$$

Substituting equations (B10), (B11), and (B15) into equation (B9) and integrating yields the desired relationships

$$q_p = 2S(1 - R)\alpha_p F_1 \pi r_v^2 \qquad T_p = \text{constant} \tag{B16a}$$

and

$$\frac{q_p}{4\pi r_v^2} = \frac{S(1 - R)\alpha_p F_1}{2} \qquad T_p = \text{constant} \tag{B16b}$$

where

$$F_1 = \frac{1 - \left[1 - \left(\frac{r_p}{D}\right)^2\right]^{1/2}}{4} \tag{B16c}$$

The planet heat rate per unit area impinging on the spherical vehicle is

$$\frac{q_p}{A_v} = 2S(1 - R)F_1 \qquad T_p = \text{constant} \tag{B16d}$$

A derivation not based on Seavey's theorem can also be made and will be presented in condensed form. The heat emitted from planet element dA_p (fig. B-3) and absorbed by a satellite of radius r_v is

$$dq_p = \frac{E_p \cos \phi_p \cos \phi_v \, dA_p \alpha_p \epsilon_p \pi r_v^2}{\pi \ell^2} \tag{B17}$$

Again substituting $\epsilon_p = 1$, $\phi_v = 0$, and $E_p = S(1 - R)/4$ and integrating, equation (B17) becomes

$$q_p = \frac{S(1 - R)r_v^2 \alpha_p}{4} \iint \frac{\cos \phi_p}{\ell^2} dA_p \tag{B18}$$

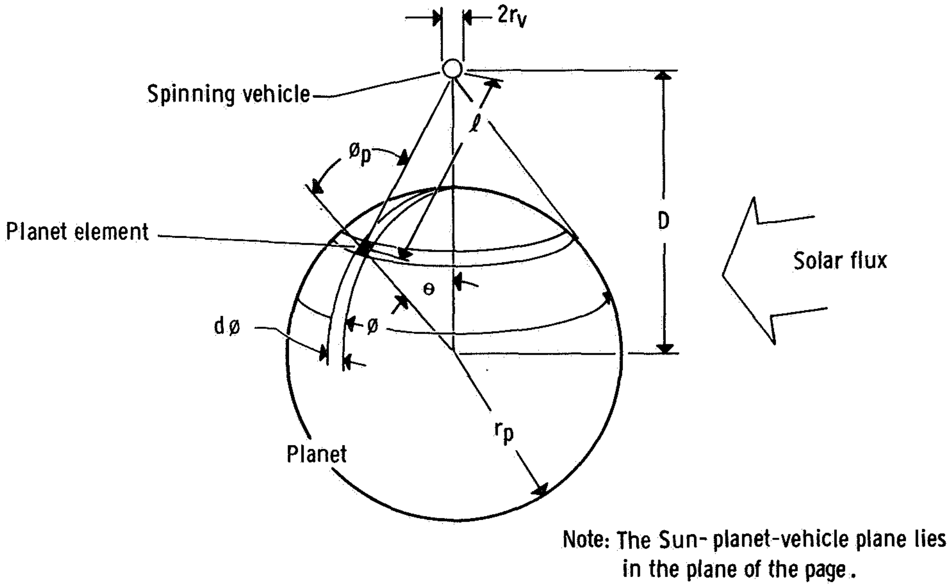


Figure B-3. - Geometry for determining heat exchange between planet and spinning vehicle.

It can be shown that

$$\cos \phi_p = \frac{D \cos \theta - r_p}{\ell} \tag{B19}$$

$$\ell^2 = r_p^2 + D^2 - 2r_p D \cos \theta \tag{B20}$$

and

$$dA_p = r_p^2 \sin \theta \, d\theta \, d\phi \tag{B21}$$

where the variables are illustrated in figure B-3. Equations (B19) to (B21) were used in reference to evaluate an expression similar to equation (B18), and from this work

the following equality can be developed

$$\iint \frac{\cos \phi_p}{\ell^2} dA_p = 2\pi \left\{ 1 - \left[1 - \left(\frac{r_p}{D} \right)^2 \right]^{1/2} \right\} \tag{B22}$$

Combining equation (B22) with equation (B18) gives

$$q_p = \frac{S(1 - R)\alpha_p}{2} \left\{ 1 - \left[1 - \left(\frac{r_p}{D} \right)^2 \right]^{1/2} \right\} \pi r_v^2 \qquad T_p = \text{constant} \tag{B23}$$

which is equivalent to equation (B16a).

Planet Heat Flux for a Spinning Vehicle and Variable Moon Temperature

Equation (B17) for radiant heat exchange between a surface differential element and a spherical satellite is applicable also to a variable Moon temperature. If the Moon has a negligible atmosphere and is a good thermal insulator, the element dA_p is in thermal equilibrium. That is, if mechanisms for heat transfer do exist (for example, conduction and convection in a planet atmosphere) so that dA_p is not in equilibrium, the surface temperatures tend to approach an average value. Also, the presence of an atmosphere, which may change considerably from one orbit to the next, makes it impractical to prepare meaningful albedo input data. Thus, average albedo values are used for the planets, and the method for constant (that is, average) planet temperature is employed. Based on the correlation of independently obtained experimental data, the Moon, as "seen" by a spacecraft in lunar orbit, for all practical purposes, can be considered a smooth sphere when determining the lunar planetary heat received by a lunar-orbital vehicle. Therefore, the heat emitted is equivalent to the solar heat absorbed, as shown in figure B-4, and

$$E_p = q_{in} = q_{out} = S(1 - R)\cos \beta \tag{B24}$$

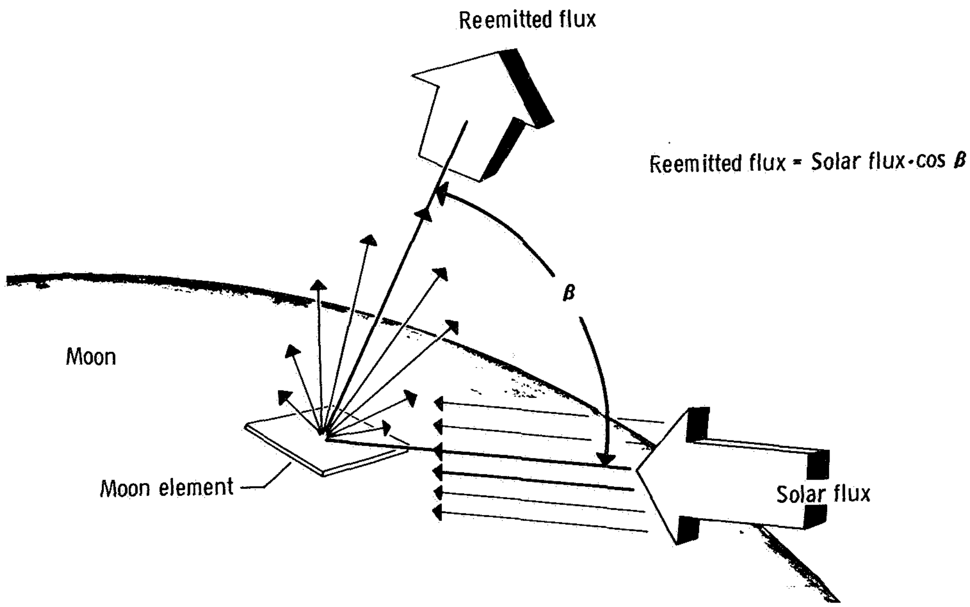


Figure B-4. - Heat emitted by an element of a variable-temperature Moon.

Combining equations (B17) and (B24), letting $\epsilon_p = 1$ and $\phi_v = 0$, integrating, and rearranging yields

$$q_p = 4\left[\frac{S(1 - R)r_v{}^2\alpha_p}{4}\right]\iint \cos\beta \frac{\cos\phi_p}{\ell^2}\, dA_p \tag{B25}$$

The function $\cos\beta$ is shown to be

$$\cos\beta = \cos\theta \cos\theta_s + \sin\theta \sin\theta_s \cos\phi \tag{B26}$$

which can be approximated by

$$\cos\beta \approx \cos\theta_s \tag{B27}$$

Equation (B27) can be mathematically substantiated for small values of θ since

$$\lim_{\theta \to 0} \cos \beta = \cos \theta_s \tag{B28}$$

For larger values of θ, the altitude is large and F is small; consequently, the error introduced by the approximation is relatively insignificant. Combining equations (B25) and (B27) gives

$$q_p \approx 4 \cos \theta_s \left[\frac{S(1 - R)r_v^2 \alpha_p}{4} \iint \frac{\cos \phi_p}{\ell^2} \, dA_p\right] \tag{B29}$$

Combining equations (B22) and (B29) gives

$$q_p = 8S(1 - R)\alpha_p F_2 \pi r_v^2 \qquad T_p \neq \text{constant} \tag{B30a}$$

and

$$\frac{q_p}{4\pi r_v^2} = 2S(1 - R)\alpha_p F_2 \qquad T_p \neq \text{constant} \tag{B30b}$$

where

$$F_2 \approx \left\{\frac{1 - \left[1 - \left(\frac{r_p}{D}\right)^2\right]^{1/2}}{4}\right\} \cos \theta_s \tag{B30c}$$

The variable-temperature planet heat rate per unit area impinging on the spherical vehicle is

$$\frac{q_p}{A_v} = 8S(1 - R)F_2 \qquad T_p \neq \text{constant} \tag{B30d}$$

An expression similar to equation (B25) has been numerically evaluated by Ballinger (ref. 6) on a digital computer. The resulting F-factors were tabulated as a function of altitude H and Sun-planet-vehicle angle θ_s. (The table of F-factors was duplicated at MRI as part of a study to determine the effect of surface topology on planet thermal emission.) The approximate radiation configuration factor F_2 is related to the tabulated factor $F\left(H, \theta_s\right)$ by

$$F_2 \approx \frac{F\left(H, \theta_s\right)}{8} \tag{B31}$$

Random values of $F\left(H, \theta_s\right)/8$ and the approximate function F_2 are plotted in figure B-5. As expected, the percent deviation is small for large values of F, and the

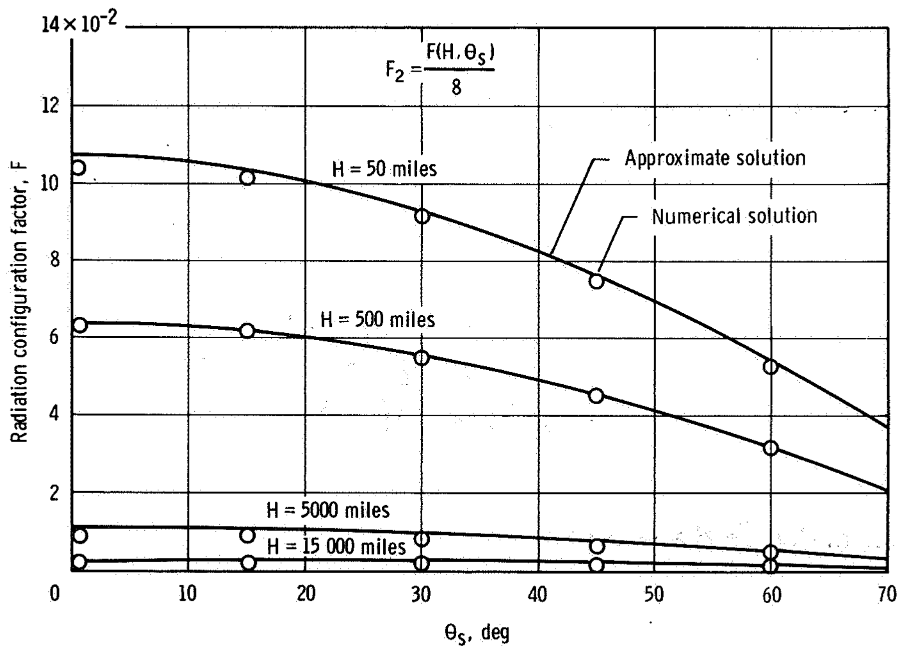


Figure B-5. - Radiation configuration factors, approximate and numerical solutions compared.

magnitude of deviation is negligible for low values of F; therefore, the approximation $\cos\beta \approx \cos\theta_s$ introduces insignificant errors into the derivation of F_2. Consequently, the F_2 function has been incorporated into the computer program in lieu of the slower table-reference method to obtain $F(H, \theta_s)/8$.

The dark side of a variable-temperature Moon is essentially in thermal equilibrium; therefore, the heat emitted can be derived from the relations that are applicable to a constant-temperature planet.

The emissive power is

$$E_p = \sigma T_m^{\ 4} \tag{B32}$$

where T_m is the dark-side or minimum temperature of the Moon. Combining equations (B32), (B9), (B10), and (B11) and integrating gives

$$q_p = 8\sigma T_m^{\ 4} \alpha_p F_1 \pi r_v^{\ 2} \qquad T_p \neq \text{constant (dark side of planet)} \tag{B33a}$$

and

$$\frac{q_p}{4\pi r_v^{\ 2}} = 2\sigma T_m^{\ 4} \alpha_p F_1 \qquad T_p \neq \text{constant (dark side of planet)} \tag{B33b}$$

where

$$F_1 = \frac{1 - \left[1 - \left(\frac{r_p}{D}\right)^2\right]^{1/2}}{4} \tag{B33c}$$

The heat impinging on the sphere is

$$\frac{q_p}{A_v} = 8\sigma T_m^{\ 4} F_1 \qquad T_p \neq \text{constant (dark side of planet)} \tag{B33d}$$

Albedo Heat Flux for a Spinning Vehicle

Solar radiation reflects diffusely from celestial bodies; therefore, the equations derived to express planetary diffuse thermal emission can be modified to be applicable to albedo calculations. Albedo includes solar energy bounced or scattered from the atmosphere above dA_p, as well as solar energy reflected from the planet surface element. The heat reflected from differential element dA_p (fig. B-3) and absorbed by A_v is given by the familiar relationship

$$dq_{albedo} = \frac{E_p \cos \phi_p \, dA_p \alpha_s \epsilon_s \pi r_v^2}{\pi \ell^2} \tag{B34}$$

where E_p is the effective emissive power of the element

$$E_p = SR \cos \beta \tag{B35}$$

Combining equations (B34) and (B35), letting $\epsilon_s = 1$, simplifying, and integrating gives

$$q_{albedo} = SRr_v^2 \alpha_s \iint (\cos \beta)\left(\frac{\cos \phi_p}{\ell^2} dA_p\right) \tag{B36}$$

Introducing the approximation $\cos \beta \approx \cos \theta_s$, equation (B36) becomes

$$q_{albedo} = SRr_v^2 \alpha_s \cos \theta_s \iint \frac{\cos \phi_p}{\ell^2} dA_p \tag{B37}$$

Substituting equation (B22) into equation (B37) gives

$$q_{albedo} = 8SR\alpha_s F_2 \pi r_v^2 \tag{B38a}$$

and

$$\frac{q}{4\pi r_v^2} = 2SR\alpha_s F_2 \tag{B38b}$$

where

$$F_2 \approx \left\{ \frac{1 - \left[1 - \left(\frac{r_p}{D}\right)^2\right]^{1/2}}{4} \right\} \cos \theta_s \tag{B38c}$$

The albedo heat rate per unit area impinging on the spherical vehicle is

$$\frac{q_{albedo}}{A_v} = 8SRF_2 \tag{B38d}$$

Planet Heat Flux for an Oriented Vehicle and Variable Moon Temperature

Equations that express the amount of thermal radiation received by a flat element in space can be derived from equation (B7). The derivations for a flat element are similar to the derivations for a sphere; however, the plate is not necessarily symmetrical with respect to the vehicle-planet line; consequently, the orientation of the plate is difficult to define. The heat absorbed by the flat-plate element (fig. B-6) from the variable surface temperature of the Moon is

$$dq_p = \frac{E_p \cos \phi_p \cos \phi_v \, dA_p \alpha_p \epsilon_p A_v}{\pi \ell^2} \tag{B39}$$

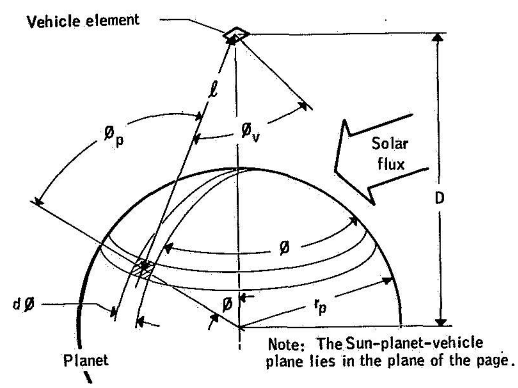


Figure B-6. - Geometry for determining heat between planet and vehicle element.

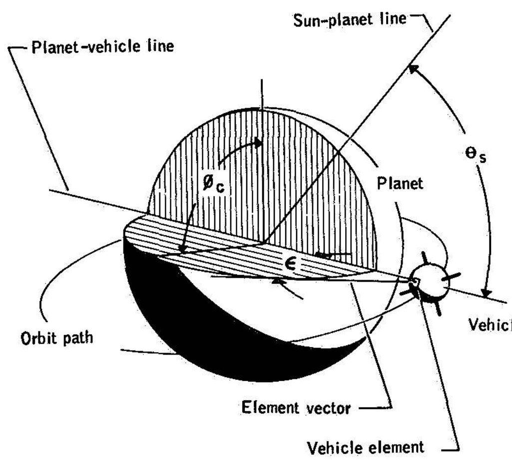


Figure B-7. - Angular variables for determining radiation configuration factors of oriented vehicles.

Substituting $\epsilon_p = 1$ and $E_p = S(1 - R)\cos\beta$ (eq. (B24)) into equation (B39) and integrating yields

$$q_p = S(1 - R)\alpha_p A_v \iint \frac{\cos\beta \cos\phi_p \cos\phi_v}{\pi\ell^2} dA_p \tag{B40}$$

An equation similar to equation (B40) was numerically integrated in reference 6, and the following equality was developed.

$$\iint \frac{\cos\beta \cos\phi_p \cos\phi_v}{\pi\ell^2} dA_p = F_3\left(H, \theta_s, \phi_c, \epsilon\right) \tag{B41}$$

where H is vehicle altitude, and the parameters θ_s, ϕ_c, and ϵ are illustrated in figure B-7. Values of F_3 as a function of the four independent variables have been calculated and tabulated. The validity of the radiation-configuration-factor table was investigated and established by hand calculations for numerous special cases and for two general cases.

Combining equations (B40) and (B41) gives

$$q_p = S(1 - R)\alpha_p F_3 A_v \qquad T_p \neq \text{constant} \tag{B42a}$$

and

$$\frac{q_p}{A_v} = S(1 - R)\alpha_p F_3 \qquad T_p \neq \text{constant} \tag{B42b}$$

where values of F_3 are found by reference to the radiation-configuration-factor table. The planet heat rate per unit area impinging on the flat plate is

$$\frac{q_p}{A_v} = S(1 - R)F_3 \qquad T_p \neq \text{constant} \tag{B42c}$$

Planet Heat Flux for an Oriented Vehicle
and Constant Planet Temperature

The emissive power of a planet of uniform temperature is independent of β; $E_p = S(1 - R)/4$, as in equation (B15). Substituting the expression for E_p into equation (B39) and integrating gives

$$q_p = \frac{S(1 - R)\alpha_p A_v}{4} \iint \frac{\cos \phi_p \cos \phi_v}{\pi \ell^2} dA_p \tag{B43}$$

Comparing equations (B41) and (B43), it is seen that

$$\iint \frac{\cos \phi_p \cos \phi_v}{\pi \ell^2} dA_p = \iint \frac{\cos (\beta = 0)\cos \phi_p \cos \phi_v}{\pi \ell^2} dA_p \tag{B44}$$

Introducing the approximation $\cos \beta \approx \cos \theta_s$, which was previously shown to have a negligible effect on accuracy, equation (B44) becomes

$$\iint \frac{\cos \phi_p \cos \phi_v}{\pi \ell^2} dA_p \approx F_3\left(H, \theta_s = 0, \phi_c, \epsilon\right) \tag{B45}$$

Combining equations (B45) and (B43) gives

$$q_p = \frac{S(1 - R)\alpha_p F_4 A_v}{4} \qquad T_p = \text{constant} \tag{B46a}$$

and

$$\frac{q_p}{A_v} = \frac{S(1 - R)\alpha_p F_4}{4} \qquad T_p = \text{constant} \tag{B46b}$$

where values of F_4 are found by reference to the radiation-configuration-factor table and are the same as F_3, except for one of the independent variables θ_s that is treated as a constant zero. The impinging heat rate is

$$\frac{q_p}{A_v} = \frac{S(1 - R)F_4}{4} \qquad T_p = \text{constant} \tag{B46c}$$

The dark side of the variable-temperature Moon is essentially in thermal equilibrium; therefore, the heat emitted can be derived from the equations that are applicable to a planet of uniform temperature.

Substituting the emissive power $\left(E_p = \sigma T_m^4\right)$ of the element shown in figure B-6 into equation (B39), integrating, and introducing the equality given in equation (B45) gives

$$q_p = \sigma T_m^4 \alpha_p F_4 A_v \qquad T_p \neq \text{constant (dark side of Moon)} \tag{B47a}$$

and

$$\frac{q_p}{A_v} = \sigma T_m^4 \alpha_p F_4 \qquad T_p \neq \text{constant (dark side of Moon)} \tag{B47b}$$

where F_4 is found by reference to the radiation-configuration-factor table. The incident heat rate is

$$\frac{q_p}{A_v} = \sigma T_m^4 F_4 \qquad T_p \neq \text{constant (dark side of Moon)} \tag{B47c}$$

Albedo Heat Flux for an Oriented Vehicle

The solar heat reflected from dA_p and absorbed by A_v (fig. B-6) is

$$dq_{albedo} = \frac{E_p \cos \phi_p \cos \phi_v \, dA_p \alpha_s \epsilon_s A_v}{\pi \ell^2} \tag{B48}$$

Substituting the effective emissive power of the planet element (eq. (B35)), letting $\epsilon_s = 1$, simplifying, and integrating gives

$$q_{albedo} = SR\alpha_s A_v \iint \frac{\cos \beta \cos \phi_p \cos \phi_v}{\pi \ell^2} dA_p \tag{B49}$$

The desired relations are found by combining equations (B41) and (B49) to obtain

$$q_{albedo} = SR\alpha_s F_3 A_v \tag{B50a}$$

and

$$\frac{q_{albedo}}{A_v} = SR\alpha_s F_3 \tag{B50b}$$

where F_3 is found by reference to the radiation-configuration-factor table (eq. (B41)). The impinging albedo is

$$\frac{q_{albedo}}{A_v} = SRF_3 \tag{B50c}$$

APPENDIX C

DISCUSSION OF PRACTICAL INTEGRATION STEP-SIZE

The only feasible method to increment time in the numerical integration of the governing temperature equation is to increment the true anomaly and compute the corresponding change in time. (Refer to the section of this report entitled "Transient Temperatures.") This procedure is expressed mathematically as

$$\phi_{n+1} = \phi_n + \Delta\phi \tag{C1}$$

and

$$\Delta t_{n+1} = t(\phi_{n+1}) - t(\phi_n) \tag{C2}$$

where $\Delta\phi$ is a constant.

Since the analysis is applicable to all planet orbits, the magnitude of Δt_{n+1} depends not only on $\Delta\phi$, but also upon variables such as orbit eccentricity, semimajor axis, vehicle position in orbit, and planet being orbited. This dependence is illustrated by comparing times that correspond to a fixed true anomaly for three Earth satellites. For $\Delta\phi = 1^\circ$, Δt is 0.3 minute for Explorer, which was put into a low circular orbit; Δt is 4.0 minutes for Syncom, which is in a large circular orbit; and Δt varies from about 0.3 to 10.0 minutes for Eccentric Geophysical Observatory (EGO), which is in a large, eccentric orbit. These widely varying times are one reason why it is necessary to refer to the length of the integration interval in terms of practicality rather than as a fixed $\Delta\phi$.

There are three conditions that can make the integration interval impractical. Two of these are controlled by the computer program. The conditions and the control on them are described, as follows:

1. The magnitude of Δt_{n+1} can be so large that the one-step truncation error temporarily influences the accuracy of the integration. To minimize computation time, the integration interval should be large as d^2T/dt^2 approaches zero; and to insure an accurate solution, the integration interval should be small as d^2T/dt^2

becomes large. This philosophy is expressed mathematically as

$$\Delta t_1' \propto \left(\frac{d^2T_n}{dt_n^2}\right)^{-1} \tag{C3}$$

The increment $\Delta t_1'$ is calculated from this equation.

2. The magnitude of Δt_{n+1} can be so large that the equilibrium temperature is reached and vastly exceeded within one integration interval, thus causing the solution to be unstable. This condition occurs if $dT/dt >> 1$, which could be caused by a vehicle skin with negligible heat capacity $\left(\rho C_p h \rightarrow 0\right)$ or by an unrealistic initial temperature T_o. The time increment $\Delta t_2'$ required to reach equilibrium temperature in one interval is calculated.

The intervals $\Delta t_1'$, $\Delta t_2'$, and Δt_{n+1} are compared, and the smallest value is selected and used to integrate the appropriate temperature equation numerically. If the computer program subdivides the time increment Δt_{n+1} into two or more values of $\Delta t'$, the entire procedure is repeated until $\Sigma \Delta t' = \Delta t_{n+1}$.

3. An impractical interval exists if $\Delta \phi$ is so large that the assumption of constant heat fluxes within the interval is absurd. The computer program will not use time increments that are larger than those computed from the value of $\Delta \phi$ in the input data; therefore, the program user must exercise judgment in choosing $\Delta \phi$ so that it is small enough to be meaningful but large enough to allow fast computation.

APPENDIX D

SUPPLEMENTARY INFORMATION FOR DATA PREPARATION

The following supplementary information is provided to the program user to aid him in preparing data in accordance with appendix I.

Summary of Coordinate Systems

A summary of coordinate systems (described in detail in the section of this report entitled "Celestial Mechanics Theory: Coordinate Systems") is provided in table D-I as a ready reference in preparing data in accordance with appendix I entitled "Program User's Guide for Data Preparation."

Planet Data Used by the Computer Program

Planet data stored in the computer program are listed in table D-II.

Sample Data Preparation for Right Ascension and Declination of the Sun from an Ephemeris

In preparing data, the user has an option in appendix I on the card type 05 to express directly the position of the Sun with respect to the planet X_p, Y_p, and Z_p coordinate axes in terms of α, β, and γ, as shown in figure 9; or they can be calculated by the computer program from five input variables: Ω, ω, i, RA, and DEC (figs. 5 and 8).

The angles RA and DEC, which are illustrated in figure 8, can be obtained for each day of the year from an ephemeris. Sample calculations for Earth, a planet (Mars), and the Moon are illustrated below for July 2, 1963, using the American Ephemeris and Nautical Almanac (ref. 1).

For Earth, RA and DEC are determined from apparent right-ascension and apparent declination data. These data are tabulated at the top of figure D-1 in hours, minutes, and seconds (24 hours equivalent to 360°). Accordingly

$$\mathrm{RA} = \frac{6\ \mathrm{hr}\ 40\ \mathrm{min}\ 58.88\ \mathrm{sec}}{24\ \mathrm{hr}} \times 360^\circ \approx 100.2^\circ$$

and DEC $\approx 23.1^\circ$.

For a planet other than Earth, longitude and latitude data are used. The data for Mars, given in the middle of figure D-1, are converted as follows:

$$RA = 200^\circ 20' 43.5'' + 180^\circ \approx 380^\circ 21' \approx 20^\circ 21'$$

$$DEC = -(+0^\circ 53' 42.5'') \approx -0^\circ 54'$$

For the Moon, colongitude and latitude are used. The data at the bottom of figure D-1 are transformed as follows:

$$RA = 90^\circ - \text{colongitude} \approx 90^\circ - 34.71^\circ \approx 55^\circ 29'$$

$$DEC = \text{latitude} \approx -0.35^\circ$$

Possible User Modifications

For some studies, it may be desirable to modify the internally stored data. The following are means of affecting such modifications for typical changes.

Possible user change	Affected-card location
Tolerance for temperature stabilization check, computer program now uses 0.5° R	Subroutine LOOP, card number DK032490
Planet albedos, computer program now uses values in table E-II	Subroutine FREAD, card numbers DK060870 to DK060950; the subscript for the variable RR corresponds to planet code on 03 card in data input
Moon cold-side temperatures used for variable temperature case, computer program now uses 186° R	Subroutine TINPUT, card number DK020770
Solar constant = 443.0 Btu/ft^2-hr, used for 1 A.U. from the Sun and as a reference value for other distances	Subroutine TINPUT, card number DK022560

TABLE D-I. - SUMMARY OF COORDINATE SYSTEMS

Vehicle coordinate system					
Vehicle orientation	Origin of axis	Location of X_v	Location of Y_v	Location of Z_v	Location of surface element
Planet oriented	Vehicle center of mass	Line connecting centers of vehicle and planet, positive direction toward planet	In the orbital plane at right angles to X_v-axis, positive direction opposite velocity vector	Normal to orbital plane to form a right-handed coordinate system	Λ' measured from X_v toward Y_v and Ω' measured from Z_v
Sun oriented	Vehicle center of mass	Line connecting centers of vehicle and Sun, positive direction toward Sun	In the orbital plane at right angles to X_v-axis[a]	To form a right-handed coordinate system, with Z_v in same hemisphere as Z_p	Λ' measured from X_v toward Y_v and Ω' measured from Z_v
Spinning[b]					

Planet coordinate system						
Vehicle orientation	Origin of axis	Location of X_p	Location of Y_p	Location of Z_p	Location of vehicle	
					Cartesian coordinates	Polar coordinates
All	At center of mass of celestial body being orbited	Along major axis of orbit, positive direction toward perigee	Along minor axis of orbit	To form a right-handed coordinate system	X_p and Y_p (may be positive or negative)	True anomaly ϕ and distance D from principal focus to vehicle

Celestial coordinate system					
Vehicle orientation	Coordinate basis	Location of X_c	Location of Y_c	Location of Z_c	Location of Sun
About Earth	Geocentric reference, center at Earth	Positive X_c toward vernal equinox ♈	Perpendicular to X_c in plane of Earth equator	To form a right-handed coordinate system	From ephemeris, geocentric coordinate system, apparent right ascension and apparent declination
About the Moon	Selenographic, reference prime meridian of Moon, center at Moon	Positive along line connecting Moon and Earth	Perpendicular to X_c in plane of Moon equator	To form a right-handed coordinate system	From ephemeris, in selenographic coordinate system, colongitude and latitude of Sun
About a planet	Modified heliocentric, reference, center at planet	Parallel to heliocentric X-axis, positive toward vernal equinox ♈	Perpendicular to X_c in plane parallel to ecliptic	To form a right-handed coordinate system	Ephemeris gives position of planet with respect to Sun, 180° added to longitude and sign of latitude changed to obtain position of Sun with respect to planet

[a]For the special case in which the rays of the Sun are normal to the orbital plane, in addition to the stated requirements, the positive Y_v-axis must be in the same direction as the positive Y_p-axis.

[b]The X_v-, Y_v-, and Z_v-axes are not applicable to spinning vehicles.

TABLE D-II. - PLANET DATA USED BY COMPUTER PROGRAM[a]

Planet code	Planet	Distance from Sun, ft	Radius, ft	Albedo	GM_p, ft^3/sec^2
1	Earth	48.89×10^{10}	20.9×10^{6}	0.35	141×10^{14}
2	Moon	48.89	5.702	.047	1.73
3	Jupiter	255.3	229.3	.51	44 900
4	Mars	74.81	10.87	.148	15.20
5	Mercury	19.03	8.151	.058	7.66
6	Neptune	1475	81.51	.62	2435
7	Saturn	467.9	188.7	.50	13 450
8	Uranus	941.3	83.6	.66	2058
9	Venus	35.43	20.34	.76	114.8

[a]The distance from Sun and the mass data for Moon are taken from reference 7. The radius, mass, and albedo data, except for the Earth and Moon albedo that are in accordance with Apollo specifications, are taken from reference 8.

SUN, 1963 — 27

FOR 0ʰ EPHEMERIS TIME

Date		Apparent Right Ascension		Apparent Declination		Radius Vector		Semi-diameter	Equation of Time Apparent − Mean	
		h m s	s	° ′ ″	″			′ ″	m s	s
July	1	6 36 50.66	248.22	+23 10 22.5	[illegible]	1.016 6915	+ 121	15 45.40	− 3 32.12	−11.66
	2	6 40 58.88	[illegible]	23 06 31.8	[illegible]	.016 7036	79	15 45.39	3 43.78	11.40
	3	[illegible]	247.66	[illegible]	279.1	.016 7115	39	15 45.38	3 55.18	11.10
	4	6 49 14.49	247.35	22 57 37.7		.016 7154	+ [illegible]	[illegible]	[illegible]	[illegible]
	5	[illegible]	[illegible]	22 52 [illegible]		[illegible]				

MARS, 1963 — 173

HELIOCENTRIC POSITIONS FOR 0ʰ EPHEMERIS TIME
MEAN EQUINOX AND ECLIPTIC OF DATE

Date		Julian Date	Longitude	Latitude	Radius Vector	Orbital Longitude	Daily Motion	Orb. Lat.
		243	° ′ ″	° ′ ″		°	°	″
July	2	8212.5	200 20 43.5	+0 53 42.5	1.617 224	200.33278	0.463 189	+0.02
	6	8216.5	[illegible]	[illegible]	.613 476	202.18981	.465 342	.01
	10	8220.5	204 04 01.7	0 47 17.3	.609 611	204.05563	.467 579	+ .01
	14	8224.5	205 56 29.1	0 43 58.7	.605 635	205.93055	.469 896	.00
	[illegible]	[illegible]	[illegible] 30.3	[illegible]	[illegible]	[illegible]	[illegible]	− .01

314 — MOON, 1963

EPHEMERIS FOR PHYSICAL OBSERVATIONS

FOR 0ʰ UNIVERSAL TIME

Date		Age	The Earth's Selenographic Longitude		The Earth's Selenographic Latitude		Physical Libration Lg. Lt. P.A.	The Sun's Selenographic Colong.	The Sun's Selenographic Lat.	Position Angle of Axis		Position Angle of Bright Limb		Fraction Illuminated
		d	°	°	°	°	(0°.01)	°	°	°	°	°	°	
July	1	9.5	+1.28	−1.26	−6.71	+0.42	0 −4 −1	[illegible]	[illegible]	19.57	−3.19	292.1	−1.8	0.70
	2	10.5	+0.02	1.22	6.29	0.69	0 4 −1	34.71	0.35	16.38	3.91	290.3	2.6	0.78
	3	11.5	−1.20	1.12	5.60	0.95	0 4 0	[illegible]	[illegible]	12.47	4.56	287.7	3.3	0.86
	4	12.5	2.32	0.97	4.65	1.16	0 4 0	59.12	0.30	7.91	[illegible]	284.4	3.7	0.92
	5	[illegible]	[illegible]	0.80	3.49	1.35	0 4 0	71.32	0.27	[illegible]		[illegible]	[illegible]	[illegible]

Figure D-1. - Ephemeris data required for RA and DEC sample calculations.

APPENDIX E

COMPUTER PROGRAM ORGANIZATION

The FORTRAN V computer program is divided into two sections called LINK1 and LINK2. Both sections reside in core at the same time; although, LINK2 is not entered unless Stromberg-Carlson 4020 (SC-4020) plots are requested. (Refer to appendix H.) The links are not to be confused with a FORTRAN II technique in which two sections of a program share core alternately. It is important that the main program of LINK1 is named PILOT and the main program of LINK2 is named MAIN2. The MSC SC-4020 programing package, which is not included in the deck, is used by LINK2. On the Univac 1108 computers at NASA MSC, the SC-4020 routines are available from a system tape.

Simplified flow charts of LINK1 and LINK2 are given in figures E-1 and E-2. The hierarchy of subroutines in each link is shown in figures E-3 and E-4. The source deck contains comment cards that may also help the user if he should desire greater detail.

LINK1

Main routine and subroutines. - PILOT is the main routine for LINK1. The function of PILOT is to define necessary constants and call two major subroutines, TINPUT and LOOP. If plots are not requested, program control passes directly from LOOP to PILOT. When plots are requested, control goes from LOOP to MAIN2 to PILOT.

All input to the program is controlled by TINPUT. The output of headings, comments, and information used to explain and define each case are also controlled by TINPUT. Subroutine SIGBET is also called by TINPUT so that the values of Σ, β, ϕ_{in}, and ϕ_{out} will be available for printing with the case headings.

Caption pages are printed by HEAD, and FREAD is called by HEAD to read in permanent data. Permanent data such as radiation-configuration-factor tables, physical constants for the Moon and eight planets, alphabetical heading information, and frequently used constants are read in by FREAD. Also, general comments are printed by FREAD, and TABLE is called by FREAD to read in material property tables. Tables of material properties are read by TABLE and rewritten on the output tape.

New tables of internal heat loads are set up by QIIN whenever the tables are to be read in. Continuation cards are read until the table contains the specified number of entries. The table is also written on a scratch tape to be copied later on the output tape.

The angular position of the Sun relative to the orbital plane is computed by SIGBET. Two types of input data are accommodated: α, β, γ or Ω, ω, i, RA, and DEC. This routine also calls FIND to locate the Sun-shade points and SUNOR to transform element angles for the Sun-oriented cases.

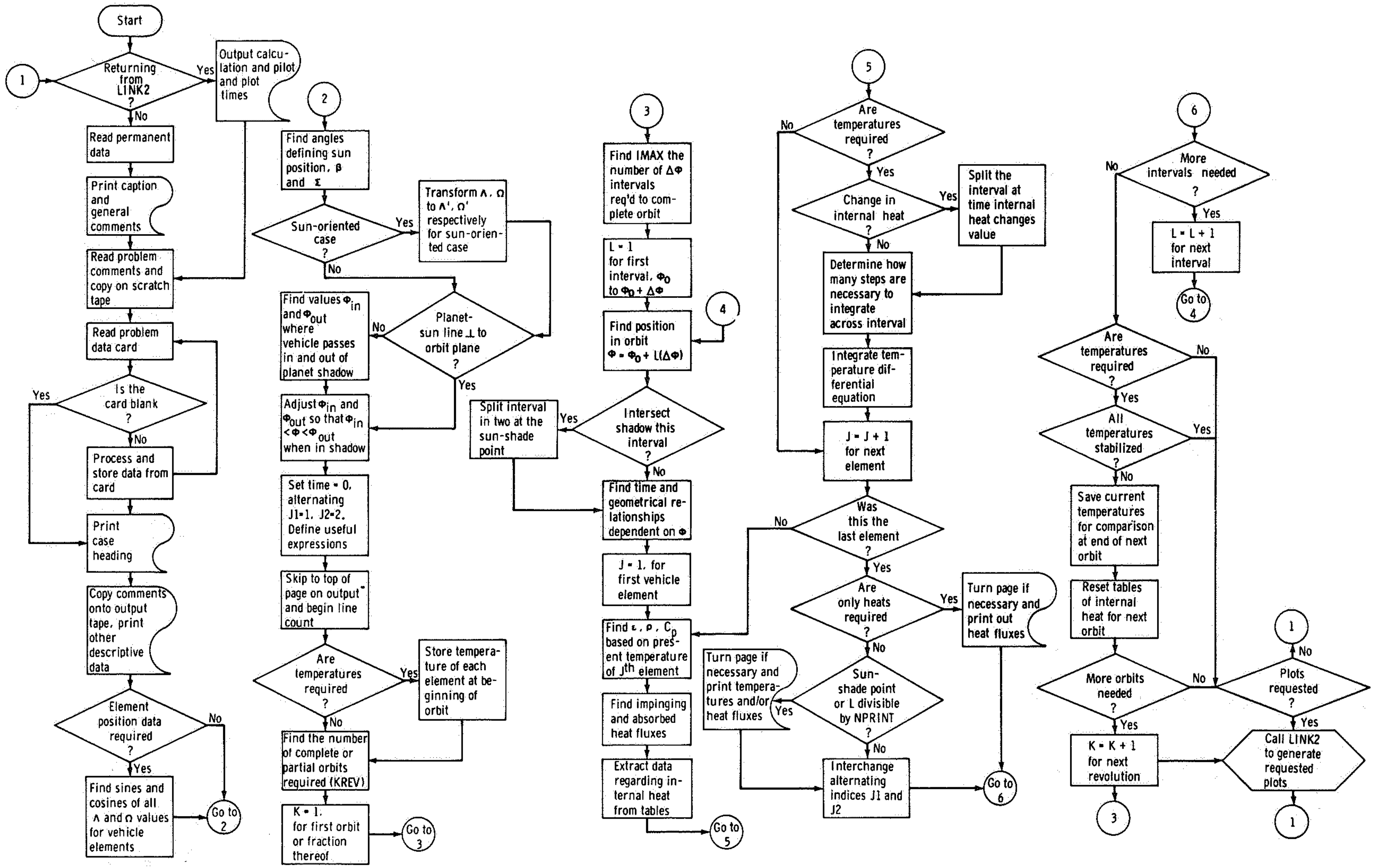


Figure E-1. - Simplified flow chart of LINK1.

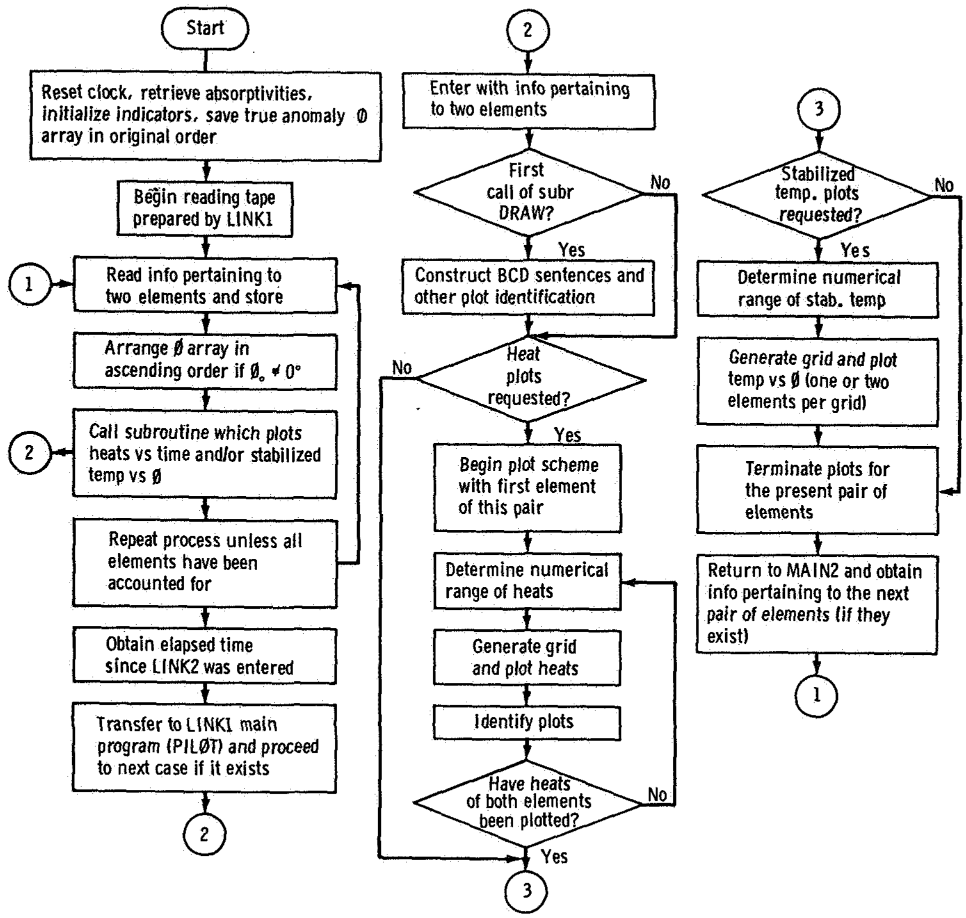


Figure E-2. - Simplified flow chart of LINK2.

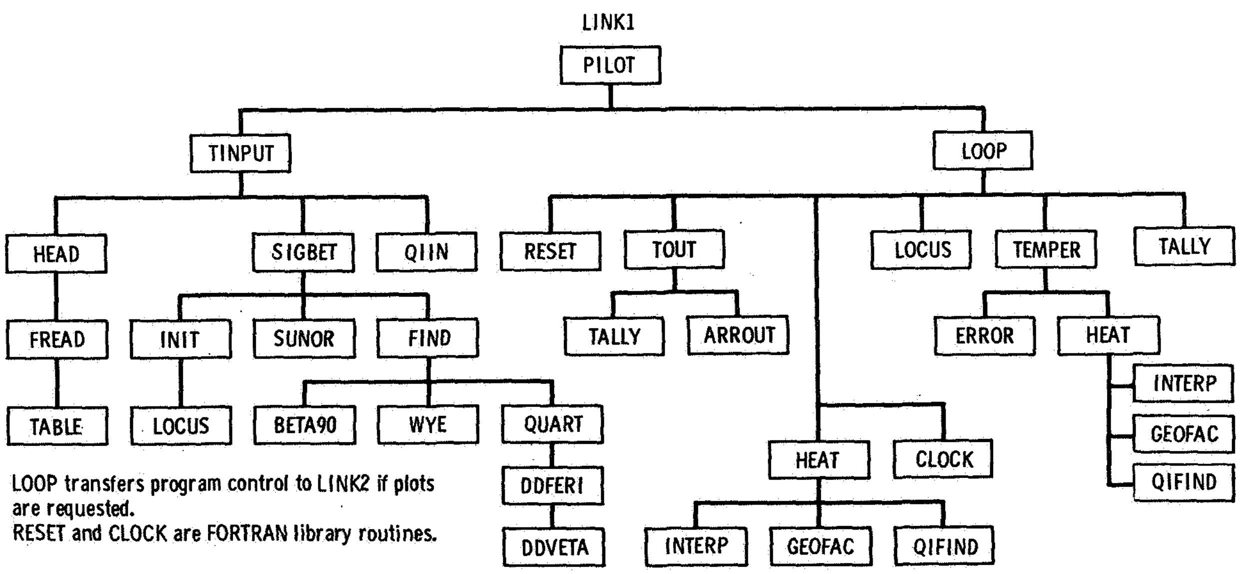
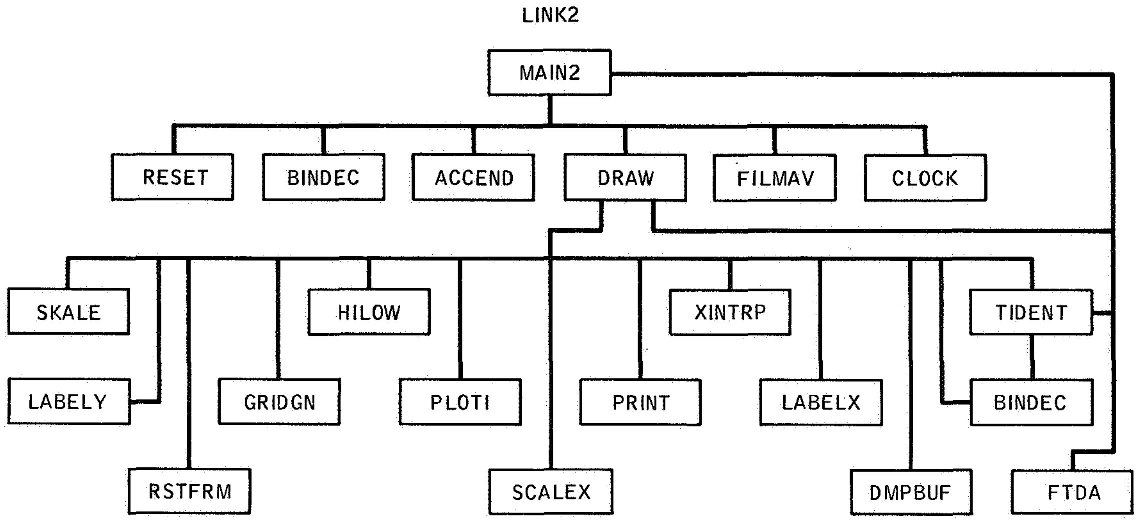


Figure E-3. - Chart of subroutine hierarchy for LINK1.



When LINK2 has completed its task, MAIN2 transfers program control to PILOT in LINK1.

RESET and CLOCK are FORTRAN library routines.

BINDEC, FILMAV, LABELY, LABELX, GRIDGN, PLOTI, PRINT, RSTFRM, SCALEX, and DMPBUF are contained in MSC SC-4020 programing package.

Figure E-4. - Chart of subroutine hierarchy for LINK2.

The quadrants of $\phi_o, \phi_{in}, \phi_{out}$ are adjusted by INIT so that $\phi_{in} < \phi < \phi_{out}$ whenever the vehicle is in the shadow. The determination whether the vehicle is initially in the Sun or in the shadow is also made by INIT.

Time, altitude, and the angle θ_s are calculated by LOCUS from ϕ, which represents the vehicle position. For oriented vehicles, ϕ_c and δ are found. The angle ϵ is also found for Sun-oriented cases. The symbols ϕ_c, θ_s, and ϵ are arguments of the radiation-configuration-factor tables, and δ is necessary to determine solar heat flux. If planet temperature T_p is variable, it is also found.

The angular coordinates of the satellite elements are converted by SUNOR from the input values to values acceptable to the program logic for Sun-oriented satellites.

The Sun-shade points ϕ_{in} and ϕ_{out} are located by FIND. If the Sun is in the orbital plane, BETA90 is called. Otherwise, QUART is called to determine the X_p value for the coordinate and WYE is called to find the Y_p value for the coordinate. Each point is examined to insure that it is not on the sunward side of the planet. The Sun-shade points for cases in which the Sun is in the orbital plane are computed by BETA90.

The Y_p values of the Sun-shade points for which the X_p values were calculated in QUART are found by WYE. Pairs of X_p and Y_p values are then examined to insure that they satisfy the equations of both the orbit ellipse and the shadow ellipse.

The roots of a quartic equation are solved for by QUART. The quartic arises when the equations for the orbit ellipse and the shadow ellipse are solved simultaneously for X_p.

DDFERI is a double-precision quartic-factorization program from the SHARE library. DDVETA is a double-precision cubic-factorization program from the SHARE library. DDVETA is required by DDFERI.

A heading to be printed at the top of an output page, and an output line count is begun by LOOP. Unless temperature calculations are not required, the maximum time interval is found for possible use in subroutine ERROR. The initial temperature of each surface element is stored for comparison with the corresponding temperatures one full orbit later.

In LINC, the number of intervals of width $\Delta\emptyset$ necessary to make one orbit is found, and in the routine KREV, the number of complete or fractional orbits that will be required, provided that all temperatures do not stabilize earlier, is found.

The vehicle is then allowed to move counterclockwise around its orbit in steps $\Delta\emptyset$. For each step, LOCUS is called to find the time and other information depending on $\emptyset$, and heat fluxes and temperatures are determined for each surface element. Output may be written after each interval $\Delta\emptyset$, or it may be deferred for two or more intervals under the control of the input parameter NPRINT.

If a Sun-shade point is reached, output occurs automatically. If temperatures are being found, the integration of the differential equation over the interval is broken into two steps at the Sun-shade point.

At the end of each complete orbit, temperatures are compared with corresponding temperatures one orbit earlier. If these agree to within 0.5° R, the case is considered finished. If not, the new temperatures are stored, the tables of internal heat loads are reset for a new orbit, and the program loops back unless the specified number of orbits read in has been exceeded. When the case is finished, control passes to PILOT or to LINK2, depending on whether or not plots were requested.

Lines of output, aside from comments, headings, and case-identifying information, are counted by TALLY. The printer carriage is restored when an output page is nearly filled. All output, except for comments, headings, and case-identifying information, are printed by TOUT. Output includes $\emptyset$, time, and either heat loads or temperatures, or both. With the normal option, data are printed in columnar format. However, an option to allow output to be printed in block form is also provided. ARROUT is an auxiliary subroutine for output of arrays of data in block form.

The subroutine HEAT is called by the subroutine TEMPER to obtain the net heat flux into each vehicle surface element and the internal heat load. The differential equation for temperature is then integrated over a given interval $\Delta\phi$ of the orbit. If the interval is too long or if internal heat loads are discontinuous within the interval, the interval is subdivided into two or more smaller steps.

A theoretical approximation to the truncation error resulting from the numerical integration is computed by ERROR. This routine is normally suppressed.

Impinging heat fluxes for a specified satellite surface element are found by HEAT. In cases for which temperature calculations are required, absorbed heat fluxes are also found, and QIFIND is called to determine the internal heat load.

Values of emittance, density, or specific heat are found by INTERP for a specified temperature by means of linear interpolation in material-property tables.

Tables of radiation configuration factors are interpolated for by GEOFAC to find a value corresponding to given ϵ, ϕ_c, θ_s, and altitude. Values of these parameters outside the range of tabulated entries are extrapolated for by the computer program. This feature is useful for θ_s greater than 90°. However, if the factor found results in a negative heat flux, subroutine HEAT will replace it by zero.

Determination of whether the internal heat for the surface element in question is varied during the interval of integration is made by the routine QIFIND. If the element is varied, initial and final heat loads and the time at which switching occurs are provided by QIFIND.

Function subroutines. - The arccosine is found in degrees of the argument by ARCOS. ARCOS always extends from 0 to 180, inclusive. PHIFN is the ratio of temperature change to time increment $\Delta T/\Delta t$, as calculated from the numerical-integration algorithm. FOFXY is the derivative of temperature with respect to time for a given temperature and location in orbit. DELTA and GFN are auxiliary functions used by ERROR.

LINK2

MAIN2 is the main routine for LINK2 and is reached whenever SC-4020 plots are requested. The primary functions of MAIN2 are to control LINK2 and to retrieve data from a scratch tape constructed by LINK1.

Identified plots of heats compared with time, stabilized temperature compared with ϕ, or both are constructed by subroutine DRAW. The ϕ array is arranged in ascending order for plot purposes by ASCEND.

A linear interpolation for ϕ, corresponding to a chosen time, is performed by XINTERP.

Minimum and maximum values of heats and temperatures are determined by HILOW for plot scaling purposes. A suitable scale and numeric labels are established by SKALE for use on plot axes. Sentences (arrays) describing temperature plots are constructed by TIDENT. IBM binary-coded-decimal data are converted to Univac field data by FTDA.

APPENDIX F

OPERATING INSTRUCTIONS

The following operating instructions are pertinent when submitting computer runs.

Tape Usage

The computer tapes used by the program are as follows:

Logical no.	Use
5	Input
6	Output
4	Scratch tape
9	Scratch tape
11	Scratch tape

Run Time on Computer

Running time varies greatly with the number and types of cases to be run. Until experience with the program enables the user to make more accurate estimates, the following suggestions are offered as a guide for running time: 0.5 minute per case for up to 10 elements and 0.5 minute per case for each additional 20 elements.

Job Submittal Sheet

When submitting the computer program to be run on one of the Univac 1108 computers at NASA MSC, the operation instructions should be as shown in figure F-1 (MSC form 588).

INSTRUCTIONS FOR SCIENTIFIC COMPUTER RUNS

(DO NOT FILL IN SHADED AREAS)

PROGRAMMER	BADGE NO.	BOX NO.	PHONE NO.	DATE
NAME, U. R.	YES	YES	YES	YES

DIVISION CODE	PROG. NO.	PROJ. NO.	EST. TIME	MAX. TIME	LINES OUTPUT
YES	YES	YES	YES	YES	YES

OPERATING SYSTEM		TYPE OF RUN	COMPUTER
1108 FORTRAN V X	FORTRAN/FAP	PROD. X TEST ☐	1108 X
1108 FORTRAN IV	IBSYS		7094
1108 COBOL	OTHER		OTHER

INPUT TAPES

UNIT	REEL	BIN NO.	DENSITY

WORKING TAPES

OUTPUT TAPES

UNIT	DEN-SITY	SAVE	PROCESSING REQUIRED

IF PLOTS ARE REQUESTED

CHECK FOR 4020 X

NO. FRAMES | PROCESSING

DUMP INSTRUCTIONS

- NO DUMP
- DUMP ON STOP
- DUMP ON LOOP
- OTHER

START

STOP

PROGRAMMER'S COMMENTS:

Note: Blocks marked "YES" must contain correct information when the program is submitted for execution.

MSC FORM 588 (REV APR 67) PREVIOUS EDITION MAY BE USED.

Figure F-1. - MSC form 588.

APPENDIX G

SAMPLE CASES

The following three sample cases are given to demonstrate to the program user the input and output format of the computer program. The sample cases were selected to show the various options available to the program user and are not necessarily realistic cases.

Problem Definition of Sample Cases

Case 501. - The problem is to determine the incident heats, absorbed heats, and temperatures of a Moon-oriented vehicle orbiting the Moon. Plots of absorbed heats versus ϕ and stabilized temperatures versus time are requested. Four surface elements are to be analyzed. Output data are to be printed every 10° for one orbit. Further specifications are as follows:

Moon surface temperature — variable

Sun position — given in an ephemeris for July 2, 1963

$i = 10°$

$\omega = 130°$

$\Omega = 70°$

Maximum orbit altitude = 165.0 n. mi.

Minimum orbit altitude = 8.73 n. mi.

$\phi_o = 0°$

$\Delta\phi = 10°$

Element 1:

$\Lambda' = 30°$, $\Omega' = 90°$

$T_o = 530°$ R

h = 0.01 ft

$Q_g = 0$

Surface area = 1.0 ft^2

Material — uncoated aluminum

Element 2:

$\Omega' = 180^\circ$ (Λ' is undefined)

$T_o = 375^\circ$ R

h = 0.005 ft

Surface area = 2.0 ft^2

All other variables same as element 1

Element 3:

$\Lambda' = 210^\circ$, $\Omega' = 90^\circ$

$T_o = 540^\circ$ R

All other variables same as element 1

Element 4:

$\Omega' = 0^\circ$ (Λ' is undefined)

$T_o = 405^\circ$ R

h = 0.005 ft

Node number = 44

All other variables same as element 1

Case 502. - The problem is to determine the incident heats, absorbed heats, and temperatures of a spinning vehicle orbiting the Earth. Plots are requested. Output data are to be printed every 30° for 7.25 orbits unless the temperatures stabilize first. Two different internal heat loads are to be compared. (This will be accomplished by running a single case using two "elements" that refer to different internal heat tables.) The following are further specifications:

Sun positions — specified in terms of α, β, and γ; date not needed

$\alpha = 80^\circ$, $\beta = 90^\circ$, $\gamma = 170^\circ$

Maximum orbit altitude = minimum orbit altitude = 181.0 n. mi.

$\phi_o = 280^\circ$

$\Delta\phi = 6^\circ$

Element 1:

$\Lambda' = 30°$, $\Omega' = 90°$

$T_o = 530° R$

$h = 0.01$ ft

$Q_g = 0$ for 15 min, then 20 Btu/ft^2-hr for 15 min

Cycle continuing throughout each orbit

Material — uncoated aluminum

Surface area = 1.0 ft^2

Element 2:

$\Omega' = 180°$ (Λ' is undefined)

$T_o = 375° R$

$Q_g = 10$ Btu/ft^2-hr continuously

Surface area = 2.0 ft^2

All other variables same as element 1

Case 503. - The problem is to determine the temperatures of a Sun-oriented vehicle orbiting the Earth. Output data are to be printed in block form every 30° for one-half of an orbit. Four surface elements are to be analyzed. The following are further specifications:

α, β, γ, minimum orbit altitude, maximum orbit altitude — same as in case 502

$\phi_o = 190°$

$\Delta\phi = 2.5°$

Element 1:

$\Lambda' = 0°$, $\Omega' = 90°$

$T_o = 530° R$

$h = 0.01$ ft

$Q_g = 0$

Material — aluminum, painted black

Surface area = $1.0\ ft^2$

Element 2:

Material — aluminum, painted white

$T_o = 375°$

Surface area = $2.0\ ft^2$

All other variables same as element 1

Element 3:

$\Lambda' = 180°$

$T_o = 540°$ R

All other variables same as element 1

Element 4:

$\Lambda' = 180°$

Material — aluminum, painted white

$T_o = 405°$ R

Node number = 44

All other variables same as element 1

Listings of Input Data

Permanent data. - The permanent data consist of 147 permanent cards that must always be present when running the computer program. They are described in the section of this report entitled "Data Deck Preparation." A complete listing is given in table G-I.

Sample-case data. - A listing of the sample-case data is defined in table G-II. The data format is described in appendix I. Several material-properties tables were prepared; however, not all the tables were used in the analysis.

Output

Reproductions of printed and plotted output from the sample cases are presented in table G-III and in figures G-1 and G-2.

TABLE G-I. - LISTING OF PERMANENT INPUT DATA

```
*      DATA
95318956825473016126476532591645082301128422791472946452541442112874145907770253
71216691616754554577355724231271076003675792544350164437372328821976110207280429
25492395220719441625127809340619048003591102103609500837070805730440031602600209
05140482044203910335027602180163013801140158014801360121010500890072005600480041
82437795721164075409424629551620097001787241689263995712485138422750150908900351
61675896548949154192333723701358087604675016480944844022343827331959117808190511
22072119197717661503121109120625049403760954091308460754064705320416030402520205
04450423039103500302025202020153012901080137012901190107009400790065005000430037
82437788720163955394423029371554084101677241688063825690482438132680147608610334
61675883546948894161330323341323084704475016479644653998340927021925114807940492
22072113196817551490119708980613048303670954091108430750064205270411030002490201
04450422039003480301025102000151012801070137012901190107009300790064005000430037
82437770717563615354418428871455079001377241684863355629475237312595138007780285
61675846541548194078320922341229076703925016476144143932333126151835106607250441
22072097194417251455115908600581045503430954090508340740063005140398028902390193
04450420038703440296024601950147012401030137012901190106009200780063004900420036
82437746713863145298412128191430072100907241680462715547465436202475126606710217
61675795534047243964308120981101065803185016471443443843322424961711095406310371
22072074191216831407110708090536041603100954089708230725061304960381027402250181
04450417038303390290023901890141011900990137012801180105009100770062004800410035
82437721710262685243405827511359065200637241676062075464455635092355114505650153
61675744526646283850295219620973054902445016466642743753311723781588084205360301
22072052187916421359105507570491037602780954088908110710059604780363025802110169
04450414037803330284023301830136011400940137012701170104009000750061004700400034
82437703707662345202401327011307060300397241672861605404448434282267105604880107
61675707521245583766285818630879047001895016463142233687303922911497076104670250
22072036185516121324101607190458034802540954088308020699058304650350024702010160
04450412037503290279022801780132011100910137012701160103008900750060004600400034
82437696706662215187399626831288058400307241671761435382445833982235102404590090
61675693519245333736282418260844044001695016461842053663301022591464073104420232
22072030184616011311100307050446033702450954088007990695057904600346024301970157
04450411037403280278022601770130010900900137012701160103008900740060004600390033
60045708529647234006316822341220067901964905472744203979341727513000117007600355
38893798357732482821233416751050075804413017297928232582226218851390093806910456
12601259120111160982082006460464037502920551054605160470041303490281021101770146
02570251023602140189016001310101008600720079007600710064005700480040003100270023
60045699528347063986314622091206068601774905471143973949338127111962113807210325
38893778354932122778226516641027070704063017296027952545221818301365088706470423
12601249118610860955079506220443035702770551054205100463040503400272020401710140
02570250023402120186015701280098008400700079007500700064005600480039003100270023
60045675524846613933308521431136061601344905466843343868328526021837101506060252
38893726347231142660212415180886058003253017290727182446210017001224075405290345
12601222114610350895072705560387030702360551053204950444038303170250018401530125
02570246022802050178014901200091007700650079007500690062005400460038002900250022
60045642520045993859300220531042052500784905460942483757315324521675085204590148
38893654336829792499194313250700042001983017283526132311193915031035058003810222
12601184109109640812063704640306023501750551051804750418035402860220015801300104
02570241022101950167013801090081006900570079007400680060005200440036002800240020
60045609515245383786291919630948043500524905455041623647302123031514069303200074
38893582326328442339176211320521027101053017276325072176177813230847041402430123
12601146103608940729054803760230017001210551050304540393032402550189013101060083
02570235021301860157012700980072006000490079007300660059005000420034002600220019
60045585511644923732285818970880037000124905450740993566292421941396057702220026
38893530318627452221162909920391016600423017271024302077166011910710029301450065
12601119099608420668048203110174012200800551049304390374030202320167011200880068
02570232020801790149011800900065005400430079007200650057004900400032002400210017
```

TABLE G-I. - LISTING OF PERMANENT INPUT DATA - Continued.

```
60045576510444763712283618730855034700034905449140763536288921541353053401870010
38893511315827092178158109400344012800203017269124022040161711430660024901090032
12601108098108230646045802870154010400660551048904340367029502230159010500820062
02570230020601770146011500870062005100410079007200650057004800400031002400200017
35523393315728252407191613670890059501612538247523302114183414981206077905530264
17701765168115471365120409400644048702971198122111771097098308640696050704060278
03060332033003240304027402360200016401300084009500980100009800950086007600650048
00260031003200320031002900250022002000170004000500050005000500050004000400030002
35523385314628112390189713460777044301422538246323122091180714671105066304430233
17701751166115211335112608510553040602621198120811581073095508160633043803430245
03060326032203100284025502060163014001120084009300920090008400760065005500490042
00260030003200300028002500230019001700150004000500050005000500040004000300030002
35523365311627732345184612900690038200982538243022642029173213830992056403520161
17701714160714511251101507380449031001811198117311071007087707150532034602550169
03060310029802750243020501650122010000790084008700840078007000600051004000340029
00260027002700250023002000170014001200100004000400040004000400030003000200020001
35523337307627212283177612140608030500512538238521981944163112690865043802380084
17701663153213561137088305990316019100941198112510370917077005930406022701500088
03060288026502330194015201110073005600410084007800720063005300430033002300190015
00260024002200200017001400110008000600050004000400030003000300020002000100010000
35523310303526692221170611380529023000172538233921321859153011540742031701350028
17701612145812601023075504640193009200321198107809670828066304750284012300660030
03060265023201910146010100620032002200140084007000600048003600240016000900070005
00260022001800140011000800050003000200010004000300030002000100000000000000000000
35523290300626312175165410830471017700022538230620831797145610700651023100680003
17701575140411900940066103650109003200041198104309160762058503890197005500180004
03060249020901610111006500300009000400010084006400510037002700160006000200010000
00260019001400100006000200010000000000000004000300020001000000000000000000000000
35523282299526172159163510620450015700002538229420651774142810390618019900440000
17701561138411640909062703290079001300001198103008980738055603570165003100040000
03060243020001500098005200180002000000000084006200480034002000100003000000000000
00260018001400090005000200000000000000000004000300020001000000000000000000000000
13511299121410910936075205450321020500880746074007030645056604710362024101780113
03690379036703430310026602150157012600940157016801660159014701300110008600730059
0                                                                              0
0                                                                              0
13511295120810840927074105340310021000720746073506950635055504580347022601650098
03690375036103350300025502030144011700810157016501620154014101230102007800650050
0                                                                              0
0                                                                              0
13511284119210630902071305030295018800350746072106750608052304220308020501480054
03690363034303130273022501800135010500500157015801510140012401040930082007000031
0                                                                              0
0                                                                              0
13511269117010340868067504620265016000250746070106460572047903730280018501280048
03690347032002830237018401450112009200350157014801360120010100850073005400450020
0                                                                              0
0                                                                              0
13511254114710060834063704200189007600150746068206180535043603240220007700300008
03690331029602520201014300810028001100030157013801210101007800520025000900450001
0                                                                              0
0                                                                              0
13511243113109850609060903900158004900010746066805970508040402880160004200070000
03690319027902300174011300510007000100000157013001100087006100340011000000000000
0                                                                              0
0                                                                              0
13511239112509780800059803780130002400050746066205890499039302750145002400050001
```

TABLE G-I. - LISTING OF PERMANENT INPUT DATA - Concluded.

```
03690314027202220164010000400002000000000157012701060082005500200000000000000000
0                                                                              0
0                                                                              0
01440141013201200104008500640040002800150015001600150014001300110009000600050004
0                                                                              0
0                                                                              0
0                                                                              0
01440140013101190103008300620038002500130015001600150014001200110008000600050003
0                                                                              0
0                                                                              0
0                                                                              0
01440138012901150098007900560032001500080015001500140013001100090007000400030002
0                                                                              0
0                                                                              0
0                                                                              0
01440135012501100092007200490020000700020015001400130012001000070005000300010000
0                                                                              0
0                                                                              0
0                                                                              0
01440133012101050086006500420017000400000015001400120010000800060004000000000000
0                                                                              0
0                                                                              0
0                                                                              0
01440131011801020082006000360011000100000015001300110009000700040002000000000000
0                                                                              0
0                                                                              0
0                                                                              0
01440130011701000081005800340007000100000015001300110009000600040001000000000000
0                                                                              0
0                                                                              0
0                                                                              0
 PLANE SATELLITE 1 PLANET TEMPERATURE IS CONSTANT      E IS VARIABLE      S SUN
ORIENTED     S SPINNING         S PLANET ORIENTED T EARTH      T MOON      T JUPI
TER   T MARS        T MERCURY    T NEPTUNE    T SATURN     T URANUS     T VENUS
```

TABLE G-II. - LISTING OF SAMPLE CASE INPUT DATA

```
10MISCELLANEOUS COMPUTATIONS FOR SPACECRAFT IN ORBIT AROUND EARTH AND MOON
10MATERIAL PROPERTIES
0602
0.          .055        9000.        .055       10000.       .3          KEAL1
0.          .970       10000.        .970                                EBP1
0.          .930        9000.        .93        10000.      .180         EWP1
0.          .36         9000.        .36        10000.      .49          EEX1
0.          .14         9000.        .14        10000.      .183         EVN1
+0        +00+22     +00+1       +05+22      +00                         ET31
0.          172.8      10000.       172.8                                KRAL1
0.          .22        10000.       .22                                  KCAL1
+0        +00+212    +00+56      +03+212     +00+66      +03+215   +00   CT31
+86       +03+228    +00+106     +04+24      +00+1       +05+24    +00   CT32
+0        +00+1728   +03+1       +05+1728    +03                         RT31
10COMPUTATION OF HEATS AND TEMPERATURES FOR FOUR ELEMENTS ON THE SURFACE OF AN
10ALUMINUM VEHICLE ORBITING THE MOON
10TEST CASE 501
01    501 4 1
02         0.       10.      1.
03 2 1 1                                           165.          8.73
04    1 62130.     90.      530.     .01     1.
04    4 6210.      0.       405.     .005    1.    44.
04    3 621210.    90.      540.     .01     1.
04    2 6210.      180.     375.     .005    2.
05         10.      130.     70.      55.29   -0.35
07    4

10 CASE TO STUDY EFFECT OF SWITCHING FREQUENCY OF INTERNAL HEAT LOADS
10TEST CASE 502
01    502 4 1
02 5       280.     6.       7.25
03 1                                               181.          181.
04    1    2
04    2    3                          .01
05 3       80.      90.      170.
06 2 8     0.       15.      20.      30.     0.    45.          20.
0660.      0.       75.      20.      90.     0.    105.         20.
06120.     0.
06 3 1     10.      90000.   10.
07    2

10TEST CASE 503
01    503 1
0212 359   190.     2.5      .5
03 1-1                                             181.          181.
04    1 2110.
04    2 3110.      90.
04    3 211180.
04    4 311180.    90.               .01
07    4
```

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES

```
MISCELLANEOUS COMPUTATIONS FOR SPACECRAFT IN ORBIT AROUND EARTH AND MOON

MATERIAL PROPERTIES

COATING MATERIAL  1 IS    KEAL1
    0.0000000     5.5000000-02    9.0000000+03    5.5000000-02    1.0000000+04    3.0000000-01
    0.0000000

COATING MATERIAL  2 IS    EBP1
    0.0000000     9.7000000-01    1.0000000+04    9.7000000-01   -0.0000000

COATING MATERIAL  3 IS    EWP1
    0.0000000     9.3000000-01    9.0000000+03    9.3000000-01    1.0000000+04    1.8000000-01
    0.0000000

COATING MATERIAL  4 IS    EEX1
    0.0000000     3.6000000-01    9.0000000+03    3.6000000-01    1.0000000+04    4.8999999-01
    0.0000000

COATING MATERIAL  5 IS    EVN1
    0.0000000     1.3999999-01    9.0000000+03    1.3999999-01    1.0000000+04    1.8300000-01
    0.0000000

COATING MATERIAL  6 IS    ET31
    0.0000000     2.2000000-01    1.0000000+04    2.2000000-01   -0.0000000

SUBSTRATE MATERIAL  1 IS    KRAL1
    0.0000000     1.7280000+02    1.0000000+04    1.7280000+02   -0.0000000

SUBSTRATE MATERIAL  1 IS    KCAL1
    0.0000000     2.2000000-01    1.0000000+04    2.2000000-01   -0.0000000

SUBSTRATE MATERIAL  2 IS    CT32
    0.0000000     2.1200000-01    5.5999999+02    2.1200000-01    6.6000000+02    2.1500000-01
    8.6000000+02  2.2799999-01    1.0600000+03    2.3999999-01    1.0000000+04    2.3999999-01
    0.0000000

SUBSTRATE MATERIAL  2 IS    RT31
    0.0000000     1.7280000+02    1.0000000+04    1.7280000+02   -0.0000000
```

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

```
CASE NO.   501
COMPUTATION OF HEATS AND TEMPERATURES FOR FOUR ELEMENTS ON THE SURFACE OF AN
ALUMINUM VEHICLE ORBITING THE MOON
TEST CASE 501
PLANET MOON               SATELLITE IS PLANET ORIENTED        PLANET TEMPERATURE IS VARIABLE
  MAX. * ORBIT ALT.(NM) * MIN.    PHIO        DPHI        SIGMA       BETA        PHIN        PHOUT
    165.00                8.73     .00000    10.00000   215.44510    87.81780   318.71390   100.61537
INCLINATION=  10.00000  ARGUMENT OF PERIFOCUS= 130.00000  LONG. OF ASC. NODE=  70.00000
 RIGHT ASCENSION=  55.29000  DECLINATION=   -.35000

ELEMENT COATING SUBSTRATE DUTY CYCLE    LAMDA       OMEGA       T(0)       THICKNESS    AREA    NODE NO.
    1       6        2          1       30.         90.         530.         .01        1.
    4       6        2          1       0.          0.          405.         .005       1.        44.
    3       6        2          1       210.        90.         540.         .01        1.
    2       6        2          1       0.          180.        375.         .005       2.

MAXIMUM NO. OF ORBITS REQUESTED=  1.000
```

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

PHI	TIME		TEMPERATURE	INCIDENT (BTU/HR-FT**2) QSOLAR	QALBEDO	QPLANET	ABSORBED (BTU/HR) QSOLAR	QALBEDO	QPLANET	QTOTAL
10.0	2.94	1	526.12	.00	.00	1.76	.00	.00	.39	.39
		2	373.07	.00	.00	.80	.00	.00	.35	.35
		3	535.77	.00	.00	.04	.00	.00	.01	.01
		44	402.36	.00	.00	.80	.00	.00	.18	.18
20.0	5.90	1	522.34	.00	.00	1.75	.00	.00	.38	.38
		2	371.17	.00	.00	.78	.00	.00	.34	.34
		3	531.66	.00	.00	.04	.00	.00	.01	.01
		44	399.79	.00	.00	.78	.00	.00	.17	.17
30.0	8.88	1	518.64	.00	.00	1.73	.00	.00	.38	.38
		2	369.29	.00	.00	.76	.00	.00	.34	.34
		3	527.63	.00	.00	.03	.00	.00	.01	.01
		44	397.25	.00	.00	.76	.00	.00	.17	.17
40.0	11.90	1	515.00	.00	.00	1.70	.00	.00	.37	.37
		2	367.43	.00	.00	.74	.00	.00	.32	.32
		3	523.68	.00	.00	.03	.00	.00	.01	.01
		44	394.75	.00	.00	.74	.00	.00	.16	.16
50.0	14.97	1	511.40	.00	.00	1.67	.00	.00	.37	.37
		2	365.57	.00	.00	.71	.00	.00	.31	.31
		3	519.78	.00	.00	.03	.00	.00	.01	.01
		44	392.27	.00	.00	.71	.00	.00	.16	.16
60.0	18.10	1	507.83	.00	.00	1.63	.00	.00	.36	.36
		2	363.72	.00	.00	.67	.00	.00	.29	.29
		3	515.92	.00	.00	.02	.00	.00	.00	.00
		44	389.80	.00	.00	.67	.00	.00	.15	.15
70.0	21.30	1	504.28	.00	.00	1.59	.00	.00	.35	.35
		2	361.86	.00	.00	.62	.00	.00	.27	.27
		3	512.09	.00	.00	.02	.00	.00	.00	.00
		44	387.34	.00	.00	.62	.00	.00	.14	.14
80.0	24.58	1	500.75	.00	.00	1.54	.00	.00	.34	.34
		2	359.99	.00	.00	.57	.00	.00	.25	.25
		3	508.28	.00	.00	.01	.00	.00	.00	.00
		44	384.87	.00	.00	.57	.00	.00	.13	.13
90.0	27.94	1	497.22	.00	.00	1.49	.00	.00	.33	.33
		2	358.10	.00	.00	.52	.00	.00	.23	.23
		3	504.49	.00	.00	.00	.00	.00	.00	.00
		44	382.41	.00	.00	.52	.00	.00	.12	.12
100.0	31.40	1	493.70	.00	.00	1.45	.00	.00	.32	.32
		2	356.21	.00	.00	.50	.00	.00	.22	.22
		3	500.71	.00	.00	.00	.00	.00	.00	.00
		44	379.94	.00	.00	.50	.00	.00	.11	.11
100.5	31.58	1	493.52	.00	.00	1.45	.00	.00	.32	.32
		2	356.11	.00	.00	.49	.00	.00	.22	.22
		3	500.51	.00	.00	.00	.00	.00	.00	.00
		44	379.82	.00	.00	.49	.00	.00	.11	.11

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

				INCIDENT (BTU/HR-FT**2)			ABSORBED (BTU/HR)			
PHI	TIME		TEMPERATURE	QSOLAR	QALBEDO	QPLANET	QSOLAR	QALBEDO	QPLANET	QTOTAL
100.6	51.61	1	493.48	.00	.00	1.45	.00	.00	.32	.32
		2	356.09	.00	.00	.49	.00	.00	.22	.22
		3	500.49	39.89	.00	.00	8.78	.00	.00	8.78
		44	379.80	16.87	.00	.49	3.71	.00	.11	3.82
110.0	34.94	1	490.19	.00	.00	1.41	.00	.00	.31	.31
		2	354.31	.00	.00	.47	.00	.00	.21	.21
		3	500.61	111.25	.00	.02	24.47	.00	.00	24.48
		44	378.60	16.87	.00	.47	3.71	.00	.10	3.81
120.0	38.58	1	486.68	.00	.00	1.38	.00	.00	.30	.30
		2	352.39	.00	.00	.44	.00	.00	.20	.20
		3	503.35	183.96	.00	.06	40.47	.00	.01	40.49
		44	377.31	16.87	.00	.44	3.71	.00	.10	3.81
130.0	42.31	1	483.84	.00	.88	17.80	.00	.19	3.92	4.11
		2	351.07	.00	.40	8.05	.00	.17	3.54	3.72
		3	508.53	251.09	.00	.08	55.24	.00	.02	55.26
		44	376.67	16.87	.43	8.70	3.71	.09	1.91	5.72
140.0	46.11	1	482.57	.00	2.83	57.44	.00	.62	12.64	13.26
		2	350.71	.00	1.00	20.26	.00	.44	8.91	9.35
		3	515.87	310.58	.00	.07	68.33	.00	.02	68.34
		44	377.00	16.87	1.04	21.08	3.71	.23	4.64	8.58
150.0	49.99	1	482.99	.00	4.88	98.99	.00	1.07	21.78	22.85
		2	351.30	.00	1.58	32.06	.00	.70	14.10	14.80
		3	524.98	360.64	.00	.05	79.34	.00	.01	79.35
		44	378.29	16.87	1.62	32.95	3.71	.36	7.25	11.32
160.0	53.92	1	484.99	.00	6.81	138.12	.00	1.50	30.39	31.89
		2	352.74	.00	2.10	42.60	.00	.92	18.74	19.67
		3	535.38	399.74	.00	.03	87.94	.00	.01	87.95
		44	380.42	16.87	2.15	43.51	3.71	.47	9.57	13.76
170.0	57.89	1	488.38	.00	8.53	173.04	.00	1.88	38.07	39.95
		2	354.92	.00	2.55	51.72	.00	1.12	22.76	23.88
		3	546.50	426.69	.00	.00	93.87	.00	.00	93.87
		44	383.25	16.87	2.60	52.63	3.71	.57	11.58	15.86
180.0	61.88	1	492.94	.00	10.04	203.52	.00	2.21	44.77	46.98
		2	357.73	.00	2.95	59.89	.00	1.30	26.35	27.65
		3	557.73	440.68	.00	.00	96.95	.00	.00	96.95
		44	386.69	16.87	3.00	60.80	3.71	.66	13.38	17.75
190.0	65.87	1	498.40	.00	11.28	228.78	.00	2.48	50.33	52.81
		2	361.04	.00	3.29	66.70	.00	1.45	29.35	30.79
		3	568.47	441.28	.00	.00	97.08	.00	.00	97.08
		44	390.58	16.87	3.33	67.61	3.71	.73	14.87	19.32
200.0	69.84	1	504.39	.00	12.18	247.06	.00	2.68	54.35	57.03
		2	364.71	.00	3.57	72.30	.00	1.57	31.81	33.38
		3	578.12	428.47	.00	.03	94.26	.00	.01	94.27
		44	394.78	16.87	3.61	73.20	3.71	.79	16.10	20.61

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

				INCIDENT (BTU/HR-FT**2)			ABSORBED (BTU/HR)			
PHI	TIME		TEMPERATURE	QSOLAR	QALBEDO	QPLANET	QSOLAR	QALBEDO	QPLANET	QTOTAL
210.0	73.77	1	510.67	.00	12.85	260.46	.00	2.83	57.30	60.13
		2	368.63	.00	3.80	77.11	.00	1.67	33.93	35.60
		3	586.20	402.64	.00	.08	88.58	.00	.02	88.60
		44	399.20	16.87	3.85	78.02	3.71	.85	17.16	21.72
220.0	77.65	1	516.95	.00	13.22	267.98	.00	2.91	58.95	61.86
		2	372.70	.00	3.98	80.75	.00	1.75	35.53	37.28
		3	592.31	364.58	.01	.15	80.21	.00	.03	80.24
		44	403.70	16.87	4.03	81.66	3.71	.89	17.96	22.56
230.0	81.46	1	522.87	.00	13.20	267.68	.00	2.90	58.89	61.79
		2	376.71	.00	4.06	82.41	.00	1.79	36.26	38.05
		3	596.17	315.44	.01	.21	69.40	.00	.05	69.45
		44	408.10	16.87	4.11	83.28	3.71	.90	18.32	22.94
240.0	85.18	1	528.24	.00	12.91	261.71	.00	2.84	57.58	60.42
		2	380.54	.00	4.06	82.42	.00	1.79	36.26	38.05
		3	597.63	256.72	.01	.26	56.48	.00	.06	56.54
		44	412.26	16.87	4.11	83.28	3.71	.90	18.32	22.94
250.0	88.82	1	532.66	.00	12.08	244.98	.00	2.66	53.90	56.55
		2	383.90	.00	3.89	78.85	.00	1.71	34.69	36.41
		3	596.64	190.20	.01	.29	41.84	.00	.06	41.91
		44	415.91	16.87	3.93	79.69	3.71	.86	17.53	22.11
260.0	92.37	1	535.87	.00	10.83	219.90	.00	2.38	48.29	50.67
		2	386.58	.00	3.59	72.00	.00	1.56	31.68	33.24
		3	593.25	117.89	.01	.27	25.94	.00	.06	26.00
		44	418.84	16.87	3.59	72.82	3.71	.79	16.02	20.52
270.0	95.82	1	537.88	.00	9.15	185.91	.00	2.01	40.81	42.82
		2	388.40	.00	3.05	61.86	.00	1.34	27.22	28.56
		3	587.52	42.01	.01	.26	9.24	.00	.06	9.30
		44	420.87	16.87	3.09	62.66	3.71	.68	13.79	18.18
280.0	99.18	1	539.12	35.15	7.18	144.48	7.73	1.57	31.77	41.07
		2	389.30	.00	2.48	50.19	.00	1.09	22.09	23.17
		3	580.85	.00	.03	.60	.00	.01	.13	.14
		44	421.96	16.87	2.51	50.98	3.71	.55	11.20	15.47
290.0	102.48	1	541.28	111.25	4.70	95.39	24.47	1.03	20.99	46.50
		2	389.05	.00	1.65	33.51	.00	.73	14.75	15.47
		3	574.02	.00	.02	.47	.00	.01	.10	.11
		44	421.89	16.87	1.66	34.16	3.71	.37	7.51	11.60
300.0	105.66	1	543.81	183.96	2.07	42.04	40.47	.46	9.25	50.18
		2	387.40	.00	.65	18.79	.00	.28	5.63	5.91
		3	568.77	.00	.00	.05	.00	.00	.01	.01
		44	420.38	16.87	.66	13.32	3.71	.14	2.93	6.79
310.0	108.79	1	546.97	251.09	.00	1.67	55.24	.00	.37	55.61
		2	385.05	.00	.00	.71	.00	.00	.31	.31
		3	563.27	.00	.00	.03	.00	.00	.01	.01
		44	418.16	16.87	.00	.71	3.71	.00	.16	3.87

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

				INCIDENT (BTU/HR-FT**2)			ABSORBED (BTU/HR)			
PHI	TIME	TEMPERATURE		QSOLAR	QALBEDO	QPLANET	QSOLAR	QALBEDO	QPLANET	QTOTAL
310.0	7.58	1	533.68	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	389.76	443.00	184.71	99.02	194.92	81.27	43.57	319.76
340.0	15.17	1	536.13	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	402.95	443.00	106.64	99.02	194.92	46.92	43.57	285.41
10.0	22.75	1	543.10	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	413.89	443.00	.00	99.02	194.92	.00	43.57	238.49
28.2	27.35	1	546.57	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	419.84	443.00	.00	99.02	194.92	.00	43.57	238.49
28.3	27.37	1	546.56	.00	.00	99.02	.00	.00	21.79	21.79
		2	419.84	.00	.00	99.02	.00	.00	43.57	43.57
40.0	30.33	1	545.17	.00	.00	99.02	.00	.00	21.79	21.79
		2	420.34	.00	.00	99.02	.00	.00	43.57	43.57
70.0	37.92	1	535.95	.00	.00	99.02	.00	.00	21.79	21.79
		2	421.58	.00	.00	99.02	.00	.00	43.57	43.57
100.0	45.50	1	527.89	.00	.00	99.02	.00	.00	21.79	21.79
		2	422.78	.00	.00	99.02	.00	.00	43.57	43.57
130.0	53.08	1	526.61	.00	.00	99.02	.00	.00	21.79	21.79
		2	423.93	.00	.00	99.02	.00	.00	43.57	43.57
160.0	60.67	1	524.83	.00	.00	99.02	.00	.00	21.79	21.79
		2	425.03	.00	.00	99.02	.00	.00	43.57	43.57
171.7	63.63	1	521.76	.00	.00	99.02	.00	.00	21.79	21.79
		2	425.45	.00	.00	99.02	.00	.00	43.57	43.57
171.8	63.65	1	521.76	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	425.48	443.00	.00	99.02	194.92	.00	43.57	238.49
190.0	68.25	1	522.14	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	431.16	443.00	.00	99.02	194.92	.00	43.57	238.49
220.0	75.83	1	524.69	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	441.42	443.00	106.64	99.02	194.92	46.92	43.57	285.41
250.0	83.42	1	534.61	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	452.93	443.00	184.71	99.02	194.92	81.27	43.57	319.76
280.0	91.00	1	543.77	443.00	213.28	99.02	97.46	46.92	21.79	166.17
		2	464.81	443.00	213.28	99.02	194.92	93.84	43.57	332.33

THE OUTPUT AT TIME= 91.00 ENDS ORBIT NUMBER 1
THE TEMPERATURES OF THESE NODES STABILIZED DURING THE LAST ORBIT... 0

310.0	98.58	1	546.37	443.00	184.71	99.02	97.46	40.64	21.79	159.88

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

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CALCULATION TIME=   .07 , PLOT TIME=   .08 , TOTAL TIME FOR THIS CASE=   .15...ALL TIMES ARE IN MINUTES...


CASE NO.   502
 CASE TO STUDY EFFECT OF SWITCHING FREQUENCY OF INTERNAL HEAT LOADS
TEST CASE 502
PLANET EARTH              SATELLITE IS SPINNING                PLANET TEMPERATURE IS CONSTANT
  MAX. * ORBIT ALT.(NM) * MIN.    PHIO        DPHI        SIGMA       BETA        PHIN        PHOUT
    181.00                181.00  279.99999   6.00000   279.99999   90.00000   28.19306   171.80689
ALPHA=  80.00000  GAMMA= 169.99999

NEW DUTY CYCLES READ IN

INDEX 2
 QIN=    .0000  T=   15.00  QIN= 20.0000  T=   30.00  QIN=    .0000  T=   45.00  QIN= 20.0000  T=   60.00
 QIN=    .0000  T=   75.00  QIN= 20.0000  T=   90.00  QIN=    .0000  T=  105.00  QIN= 20.0000  T=  120.00
 QIN=    .0000  T=

INDEX 3
 QIN= 10.0000  T=90000.00  QIN= 10.0000  T=

ELEMENT COATING SUBSTRATE DUTY CYCLE     LAMDA      OMEGA      T(O)      THICKNESS    AREA    NODE NO.
   1                         2
   2                         3                                              .01

MAXIMUM NO. OF ORBITS REQUESTED=  7.250
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TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

				INCIDENT (BTU/HR-FT**2)			ABSORBED (BTU/HR)			
PHI	TIME		TEMPERATURE	QSOLAR	QALBEDO	QPLANET	QSOLAR	QALBEDO	QPLANET	QTOTAL
310.0	7.58	1	533.68	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	389.76	443.00	184.71	99.02	194.92	81.27	43.57	319.76
340.0	15.17	1	536.13	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	402.95	443.00	106.64	99.02	194.92	46.92	43.57	285.41
10.0	22.75	1	543.10	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	413.89	443.00	.00	99.02	194.92	.00	43.57	238.49
28.2	27.35	1	546.57	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	419.84	443.00	.00	99.02	194.92	.00	43.57	238.49
28.3	27.37	1	546.56	.00	.00	99.02	.00	.00	21.79	21.79
		2	419.84	.00	.00	99.02	.00	.00	43.57	43.57
40.0	30.33	1	545.17	.00	.00	99.02	.00	.00	21.79	21.79
		2	420.34	.00	.00	99.02	.00	.00	43.57	43.57
70.0	37.92	1	535.95	.00	.00	99.02	.00	.00	21.79	21.79
		2	421.58	.00	.00	99.02	.00	.00	43.57	43.57
100.0	45.50	1	527.89	.00	.00	99.02	.00	.00	21.79	21.79
		2	422.78	.00	.00	99.02	.00	.00	43.57	43.57
130.0	53.08	1	526.61	.00	.00	99.02	.00	.00	21.79	21.79
		2	423.93	.00	.00	99.02	.00	.00	43.57	43.57
160.0	60.67	1	524.83	.00	.00	99.02	.00	.00	21.79	21.79
		2	425.03	.00	.00	99.02	.00	.00	43.57	43.57
171.7	63.63	1	521.76	.00	.00	99.02	.00	.00	21.79	21.79
		2	425.45	.00	.00	99.02	.00	.00	43.57	43.57
171.8	63.65	1	521.76	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	425.48	443.00	.00	99.02	194.92	.00	43.57	238.49
190.0	68.25	1	522.14	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	431.16	443.00	.00	99.02	194.92	.00	43.57	238.49
220.0	75.83	1	524.69	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	441.42	443.00	106.64	99.02	194.92	46.92	43.57	285.41
250.0	83.42	1	534.61	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	452.93	443.00	184.71	99.02	194.92	81.27	43.57	319.76
280.0	91.00	1	543.77	443.00	213.28	99.02	97.46	46.92	21.79	166.17
		2	464.81	443.00	213.28	99.02	194.92	93.84	43.57	332.33

THE OUTPUT AT TIME= 91.00 ENDS ORBIT NUMBER 1
THE TEMPERATURES OF THESE NODES STABILIZED DURING THE LAST ORBIT... 0

310.0	98.58	1	546.37	443.00	184.71	99.02	97.46	40.64	21.79	159.88

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

PHI	TIME		TEMPERATURE	INCIDENT (BTU/HR-FT**2) QSOLAR	QALBEDO	QPLANET	ABSORBED (BTU/HR) QSOLAR	QALBEDO	QPLANET	QTOTAL
		2	475.97	443.00	184.71	99.02	194.92	81.27	43.57	319.76
340.0	106.17	1	547.82	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	485.43	443.00	106.64	99.02	194.92	46.92	43.57	285.41
10.0	113.75	1	553.84	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	492.54	443.00	.00	99.02	194.92	.00	43.57	238.49
28.2	118.35	1	556.76	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	496.16	443.00	.00	99.02	194.92	.00	43.57	238.49
28.3	118.38	1	556.75	.00	.00	99.02	.00	.00	21.79	21.79
		2	496.15	.00	.00	99.02	.00	.00	43.57	43.57
40.0	121.33	1	555.02	.00	.00	99.02	.00	.00	21.79	21.79
		2	495.17	.00	.00	99.02	.00	.00	43.57	43.57
70.0	128.92	1	545.00	.00	.00	99.02	.00	.00	21.79	21.79
		2	492.75	.00	.00	99.02	.00	.00	43.57	43.57
100.0	136.50	1	536.24	.00	.00	99.02	.00	.00	21.79	21.79
		2	490.48	.00	.00	99.02	.00	.00	43.57	43.57
130.0	144.08	1	534.34	.00	.00	99.02	.00	.00	21.79	21.79
		2	488.35	.00	.00	99.02	.00	.00	43.57	43.57
160.0	151.67	1	531.98	.00	.00	99.02	.00	.00	21.79	21.79
		2	486.34	.00	.00	99.02	.00	.00	43.57	43.57
171.7	154.63	1	528.70	.00	.00	99.02	.00	.00	21.79	21.79
		2	485.59	.00	.00	99.02	.00	.00	43.57	43.57
171.8	154.65	1	528.70	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	485.61	443.00	.00	99.02	194.92	.00	43.57	238.49
190.0	159.25	1	528.77	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	489.48	443.00	.00	99.02	194.92	.00	43.57	238.49
220.0	166.84	1	530.84	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	496.77	443.00	106.64	99.02	194.92	46.92	43.57	285.41
250.0	174.42	1	540.29	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	505.28	443.00	184.71	99.02	194.92	81.27	43.57	319.76
280.0	182.00	1	549.00	443.00	213.28	99.02	97.46	46.92	21.79	166.17
		2	514.15	443.00	213.28	99.02	194.92	93.84	43.57	332.33

THE OUTPUT AT TIME= 182.00 ENDS ORBIT NUMBER 2
THE TEMPERATURES OF THESE NODES STABILIZED DURING THE LAST ORBIT... 0

PHI	TIME		TEMPERATURE	INCIDENT (BTU/HR-FT**2) QSOLAR	QALBEDO	QPLANET	ABSORBED (BTU/HR) QSOLAR	QALBEDO	QPLANET	QTOTAL
310.0	189.59	1	551.17	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	522.30	443.00	184.71	99.02	194.92	81.27	43.57	319.76
340.0	197.17	1	552.23	443.00	106.64	99.02	97.46	23.46	21.79	142.71

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

				INCIDENT (BTU/HR-FT**2)			ABSORBED (BTU/HR)			
PHI	TIME	TEMPERATURE		QSOLAR	QALBEDO	QPLANET	QSOLAR	QALBEDO	QPLANET	QTOTAL
		2	528.77	443.00	106.64	99.02	194.92	46.92	43.57	285.41
10.0	204.75	1	557.87	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	532.99	443.00	.00	99.02	194.92	.00	43.57	238.49
28.2	209.35	1	560.58	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	534.90	443.00	.00	99.02	194.92	.00	43.57	238.49
28.3	209.38	1	560.56	.00	.00	99.02	.00	.00	21.79	21.79
		2	534.89	.00	.00	99.02	.00	.00	43.57	43.57
40.0	212.34	1	558.70	.00	.00	99.02	.00	.00	21.79	21.79
		2	532.84	.00	.00	99.02	.00	.00	43.57	43.57
70.0	219.92	1	548.37	.00	.00	99.02	.00	.00	21.79	21.79
		2	527.88	.00	.00	99.02	.00	.00	43.57	43.57
100.0	227.50	1	539.35	.00	.00	99.02	.00	.00	21.79	21.79
		2	523.29	.00	.00	99.02	.00	.00	43.57	43.57
130.0	235.09	1	537.21	.00	.00	99.02	.00	.00	21.79	21.79
		2	519.02	.00	.00	99.02	.00	.00	43.57	43.57
160.0	242.67	1	534.63	.00	.00	99.02	.00	.00	21.79	21.79
		2	515.06	.00	.00	99.02	.00	.00	43.57	43.57
171.7	245.63	1	531.27	.00	.00	99.02	.00	.00	21.79	21.79
		2	513.58	.00	.00	99.02	.00	.00	43.57	43.57
171.8	245.65	1	531.27	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	513.60	443.00	.00	99.02	194.92	.00	43.57	238.49
190.0	250.25	1	531.22	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	516.38	443.00	.00	99.02	194.92	.00	43.57	238.49
220.0	257.84	1	533.11	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	521.91	443.00	106.64	99.02	194.92	46.92	43.57	285.41
250.0	265.42	1	542.39	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	528.71	443.00	184.71	99.02	194.92	81.27	43.57	319.76
280.0	273.00	1	550.92	443.00	213.28	99.02	97.46	46.92	21.79	166.17
		2	535.91	443.00	213.28	99.02	194.92	93.84	43.57	332.33

THE OUTPUT AT TIME= 273.00 ENDS ORBIT NUMBER 3
THE TEMPERATURES OF THESE NODES STABILIZED DURING THE LAST ORBIT... 0

310.0	280.59	1	552.93	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	542.45	443.00	184.71	99.02	194.92	81.27	43.57	319.76
340.0	288.17	1	553.84	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	547.38	443.00	106.64	99.02	194.92	46.92	43.57	285.41
10.0	295.75	1	559.35	443.00	.00	99.02	97.46	.00	21.79	119.25

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

				INCIDENT (BTU/HR-FT**2)			ABSORBED (BTU/HR)			
PHI	TIME	TEMPERATURE		QSOLAR	QALBEDO	QPLANET	QSOLAR	QALBEDO	QPLANET	QTOTAL
		2	550.13	443.00	.00	99.02	194.92	.00	43.57	238.49
28.2	300.35	1	561.97	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	551.20	443.00	.00	99.02	194.92	.00	43.57	238.49
28.3	300.38	1	561.96	.00	.00	99.02	.00	.00	21.79	21.79
		2	551.18	.00	.00	99.02	.00	.00	43.57	43.57
40.0	303.34	1	560.05	.00	.00	99.02	.00	.00	21.79	21.79
		2	548.62	.00	.00	99.02	.00	.00	43.57	43.57
70.0	310.92	1	549.61	.00	.00	99.02	.00	.00	21.79	21.79
		2	542.43	.00	.00	99.02	.00	.00	43.57	43.57
100.0	318.50	1	540.48	.00	.00	99.02	.00	.00	21.79	21.79
		2	536.74	.00	.00	99.02	.00	.00	43.57	43.57
130.0	326.09	1	538.25	.00	.00	99.02	.00	.00	21.79	21.79
		2	531.48	.00	.00	99.02	.00	.00	43.57	43.57
160.0	333.67	1	535.59	.00	.00	99.02	.00	.00	21.79	21.79
		2	526.62	.00	.00	99.02	.00	.00	43.57	43.57
171.7	336.63	1	532.20	.00	.00	99.02	.00	.00	21.79	21.79
		2	524.82	.00	.00	99.02	.00	.00	43.57	43.57
171.8	336.66	1	532.20	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	524.84	443.00	.00	99.02	194.92	.00	43.57	238.49
190.0	341.25	1	532.11	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	527.13	443.00	.00	99.02	194.92	.00	43.57	238.49
220.0	348.84	1	533.93	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	531.88	443.00	106.64	99.02	194.92	46.92	43.57	285.41
250.0	356.42	1	543.15	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	537.94	443.00	184.71	99.02	194.92	81.27	43.57	319.76
280.0	364.00	1	551.62	443.00	213.28	99.02	97.46	46.92	21.79	166.17
		2	544.43	443.00	213.28	99.02	194.92	93.84	43.57	332.33

THE OUTPUT AT TIME= 364.00 ENDS ORBIT NUMBER 4
THE TEMPERATURES OF THESE NODES STABILIZED DURING THE LAST ORBIT... 0

310.0	371.59	1	553.57	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	550.28	443.00	184.71	99.02	194.92	81.27	43.57	319.76
340.0	379.17	1	554.43	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	554.57	443.00	106.64	99.02	194.92	46.92	43.57	285.41
10.0	386.75	1	559.89	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	556.71	443.00	.00	99.02	194.92	.00	43.57	238.49
28.2	391.35	1	562.48	443.00	.00	99.02	97.46	.00	21.79	119.25

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

				INCIDENT (BTU/HR-FT**2)			ABSORBED (BTU/HR)			
PHI	TIME		TEMPERATURE	QSOLAR	QALBEDO	QPLANET	QSOLAR	QALBEDO	QPLANET	QTOTAL
		2	557.44	443.00	.00	99.02	194.92	.00	43.57	238.49
28.3	391.38	1	562.47	.00	.00	99.02	.00	.00	21.79	21.79
		2	557.42	.00	.00	99.02	.00	.00	43.57	43.57
40.0	394.34	1	560.54	.00	.00	99.02	.00	.00	21.79	21.79
		2	554.65	.00	.00	99.02	.00	.00	43.57	43.57
70.0	401.92	1	550.05	.00	.00	99.02	.00	.00	21.79	21.79
		2	547.96	.00	.00	99.02	.00	.00	43.57	43.57
100.0	409.50	1	540.89	.00	.00	99.02	.00	.00	21.79	21.79
		2	541.83	.00	.00	99.02	.00	.00	43.57	43.57
130.0	417.09	1	538.63	.00	.00	99.02	.00	.00	21.79	21.79
		2	536.18	.00	.00	99.02	.00	.00	43.57	43.57
160.0	424.67	1	535.94	.00	.00	99.02	.00	.00	21.79	21.79
		2	530.97	.00	.00	99.02	.00	.00	43.57	43.57
171.7	427.63	1	532.54	.00	.00	99.02	.00	.00	21.79	21.79
		2	529.04	.00	.00	99.02	.00	.00	43.57	43.57
171.8	427.66	1	532.54	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	529.05	443.00	.00	99.02	194.92	.00	43.57	238.49
190.0	432.25	1	532.44	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	531.15	443.00	.00	99.02	194.92	.00	43.57	238.49
220.0	439.84	1	534.23	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	535.60	443.00	106.64	99.02	194.92	46.92	43.57	285.41
250.0	447.42	1	543.42	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	541.38	443.00	184.71	99.02	194.92	81.27	43.57	319.76
280.0	455.01	1	551.87	443.00	213.28	99.02	97.46	46.92	21.79	166.17
		2	547.59	443.00	213.28	99.02	194.92	93.84	43.57	332.33

THE OUTPUT AT TIME= 455.01 ENDS ORBIT NUMBER 5
THE TEMPERATURES OF THESE NODES STABILIZED DURING THE LAST ORBIT... 1

PHI	TIME		TEMPERATURE	QSOLAR	QALBEDO	QPLANET	QSOLAR	QALBEDO	QPLANET	QTOTAL
310.0	462.59	1	553.57	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	553.18	443.00	184.71	99.02	194.92	81.27	43.57	319.76
340.0	470.17	1	554.43	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	557.22	443.00	106.64	99.02	194.92	46.92	43.57	285.41
10.0	477.76	1	559.89	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	559.14	443.00	.00	99.02	194.92	.00	43.57	238.49
28.2	482.35	1	562.48	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	559.74	443.00	.00	99.02	194.92	.00	43.57	238.49
28.3	482.38	1	562.47	.00	.00	99.02	.00	.00	21.79	21.79

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

PHI	TIME	TEMPERATURE		INCIDENT (BTU/HR-FT**2) QSOLAR	QALBEDO	QPLANET	ABSORBED (BTU/HR) QSOLAR	QALBEDO	QPLANET	QTOTAL
		2	559.72	.00	.00	99.02	.00	.00	43.57	43.57
40.0	485.34	1	560.54	.00	.00	99.02	.00	.00	21.79	21.79
		2	556.86	.00	.00	99.02	.00	.00	43.57	43.57
70.0	492.92	1	550.05	.00	.00	99.02	.00	.00	21.79	21.79
		2	549.99	.00	.00	99.02	.00	.00	43.57	43.57
100.0	500.51	1	540.89	.00	.00	99.02	.00	.00	21.79	21.79
		2	543.69	.00	.00	99.02	.00	.00	43.57	43.57
130.0	508.09	1	538.63	.00	.00	99.02	.00	.00	21.79	21.79
		2	537.90	.00	.00	99.02	.00	.00	43.57	43.57
160.0	515.67	1	535.94	.00	.00	99.02	.00	.00	21.79	21.79
		2	532.56	.00	.00	99.02	.00	.00	43.57	43.57
171.7	518.63	1	532.54	.00	.00	99.02	.00	.00	21.79	21.79
		2	530.58	.00	.00	99.02	.00	.00	43.57	43.57
171.8	518.66	1	532.54	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	530.59	443.00	.00	99.02	194.92	.00	43.57	238.49
190.0	523.26	1	532.44	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	532.62	443.00	.00	99.02	194.92	.00	43.57	238.49
220.0	530.84	1	534.23	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	536.96	443.00	106.64	99.02	194.92	46.92	43.57	285.41
250.0	538.42	1	543.42	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	542.63	443.00	184.71	99.02	194.92	81.27	43.57	319.76
280.0	546.01	1	551.87	443.00	213.28	99.02	97.46	46.92	21.79	166.17
		2	548.74	443.00	213.28	99.02	194.92	93.84	43.57	332.33

THE OUTPUT AT TIME= 546.01 ENDS ORBIT NUMBER 6
THE TEMPERATURES OF THESE NODES STABILIZED DURING THE LAST ORBIT... 0

PHI	TIME	TEMPERATURE		INCIDENT QSOLAR	QALBEDO	QPLANET	ABSORBED QSOLAR	QALBEDO	QPLANET	QTOTAL
310.0	553.59	1	553.57	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	554.24	443.00	184.71	99.02	194.92	81.27	43.57	319.76
340.0	561.17	1	554.43	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	558.18	443.00	106.64	99.02	194.92	46.92	43.57	285.41
10.0	568.76	1	559.89	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	560.02	443.00	.00	99.02	194.92	.00	43.57	238.49
28.2	573.36	1	562.48	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	560.57	443.00	.00	99.02	194.92	.00	43.57	238.49
28.3	573.38	1	562.47	.00	.00	99.02	.00	.00	21.79	21.79
		2	560.55	.00	.00	99.02	.00	.00	43.57	43.57
40.0	576.34	1	560.54	.00	.00	99.02	.00	.00	21.79	21.79

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

				INCIDENT (BTU/HR-FT**2)			ABSORBED (BTU/HR)			
PHI	TIME	TEMPERATURE		QSOLAR	QALBEDO	QPLANET	QSOLAR	QALBEDO	QPLANET	QTOTAL
		2	557.67	.00	.00	99.02	.00	.00	43.57	43.57
70.0	583.32	1	550.05	.00	.00	99.02	.00	.00	21.79	21.79
		2	550.73	.00	.00	99.02	.00	.00	43.57	43.57
100.0	591.51	1	540.89	.00	.00	99.02	.00	.00	21.79	21.79
		2	544.37	.00	.00	99.02	.00	.00	43.57	43.57
130.0	599.09	1	538.63	.00	.00	99.02	.00	.00	21.79	21.79
		2	538.52	.00	.00	99.02	.00	.00	43.57	43.57
160.0	606.67	1	535.94	.00	.00	99.02	.00	.00	21.79	21.79
		2	533.13	.00	.00	99.02	.00	.00	43.57	43.57
171.7	609.63	1	532.54	.00	.00	99.02	.00	.00	21.79	21.79
		2	531.14	.00	.00	99.02	.00	.00	43.57	43.57
171.8	609.66	1	532.54	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	531.15	443.00	.00	99.02	194.92	.00	43.57	238.49
190.0	614.26	1	532.44	443.00	.00	99.02	97.46	.00	21.79	119.25
		2	533.15	443.00	.00	99.02	194.92	.00	43.57	238.49
220.0	621.84	1	534.23	443.00	106.64	99.02	97.46	23.46	21.79	142.71
		2	537.45	443.00	106.64	99.02	194.92	46.92	43.57	285.41
250.0	629.42	1	543.42	443.00	184.71	99.02	97.46	40.64	21.79	159.88
		2	543.08	443.00	184.71	99.02	194.92	81.27	43.57	319.76
280.0	637.01	1	551.87	443.00	213.28	99.02	97.46	46.92	21.79	166.17
		2	549.16	443.00	213.28	99.02	194.92	93.84	43.57	332.33

THE OUTPUT AT TIME= 637.01 ENDS ORBIT NUMBER 7
THE TEMPERATURES OF THESE NODES STABILIZED DURING THE LAST ORBIT... 2

S-C 4020 PLOTS HAVE BEEN REQUESTED AND SHALL BE PROVIDED BY LINK 2

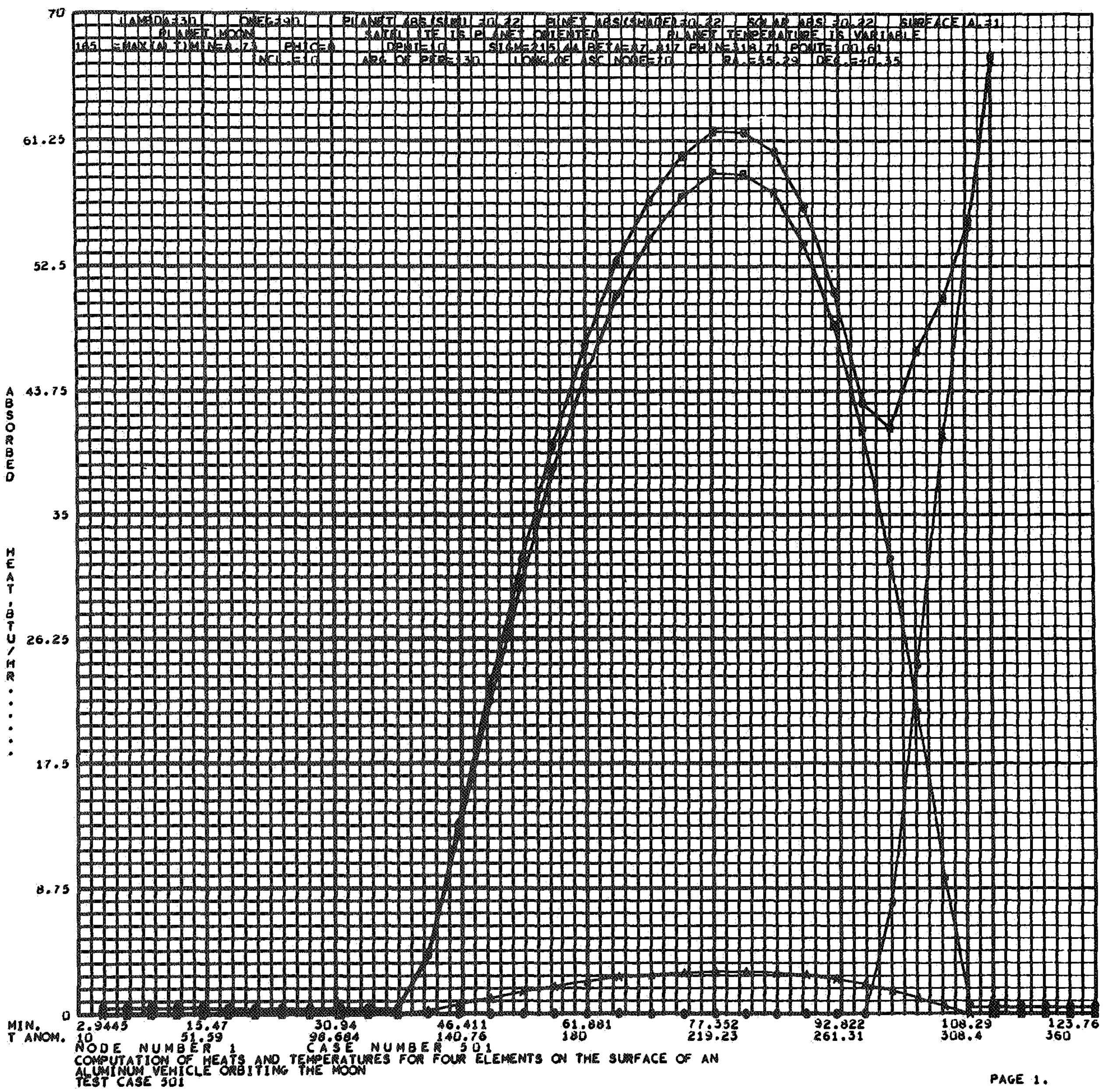
CALCULATION TIME= .67 , PLOT TIME= .05 , TOTAL TIME FOR THIS CASE= .72...ALL TIMES ARE IN MINUTES...

TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Continued

```
CASE NO.   503
TEST CASE 503
PLANET EARTH                SATELLITE IS SUN ORIENTED          PLANET TEMPERATURE IS CONSTANT
  MAX. # ORBIT ALT.(NM) # MIN.    PHIO         DPHI        SIGMA        BETA         PHIN         PHOUT
    181.00              181.00   190.00000    2.50000   279.99999    90.00000    28.19307   171.80689
ALPHA=  80.00000  GAMMA= 169.99999

ELEMENT COATING SUBSTRATE DUTY CYCLE     LAMDA       OMEGA       T(O)      THICKNESS    AREA    NODE NO.
    1       2         1          1        0.
    2       3         1          1        0.          90.
    3       2         1          1        180.
    4       3         1          1        180.        90.                     .01

MAXIMUM NO. OF ORBITS REQUESTED=   .500
```

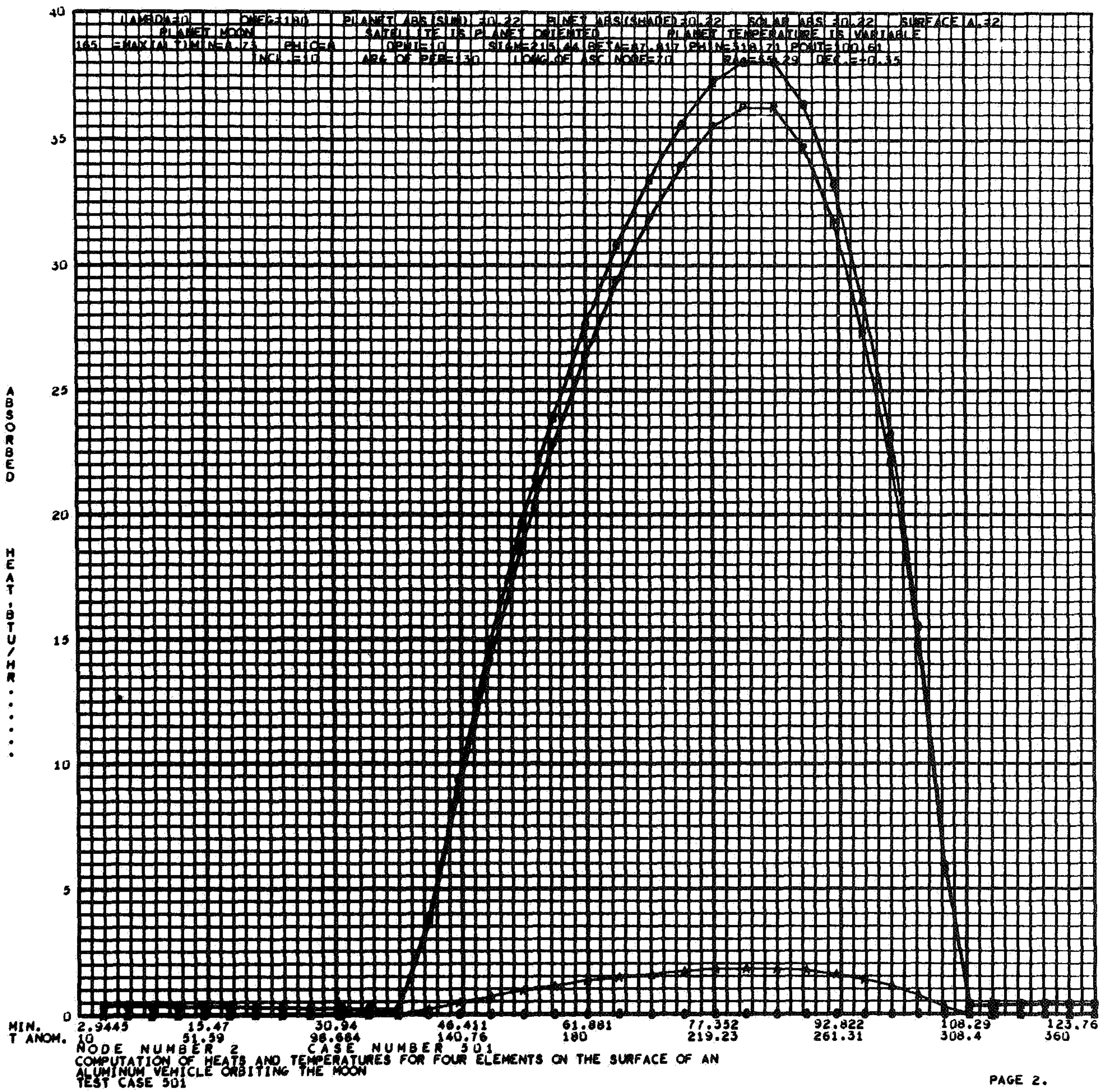
TABLE G-III. - PRINTED OUTPUT FROM SAMPLE CASES - Concluded

```
  PHI      TIME  TEMPERATURE AND/OR HEAT FLUX

220.0      7.58  TEMPERATURES
                 1       618.56     394.93     514.02     402.00

250.0     15.17  TEMPERATURES
                 1       668.06     409.14     515.41     407.41

280.0     22.75  TEMPERATURES
                 1       697.87     422.70     533.95     418.49

310.0     30.33  TEMPERATURES
                 1       706.37     431.70     545.49     427.47

340.0     37.92  TEMPERATURES
                 1       712.80     440.86     535.12     428.37

 10.0     45.50  TEMPERATURES
                 1       718.64     451.85     508.30     421.32


CALCULATION TIME FOR THIS CASE =   .18 MINUTES...
```



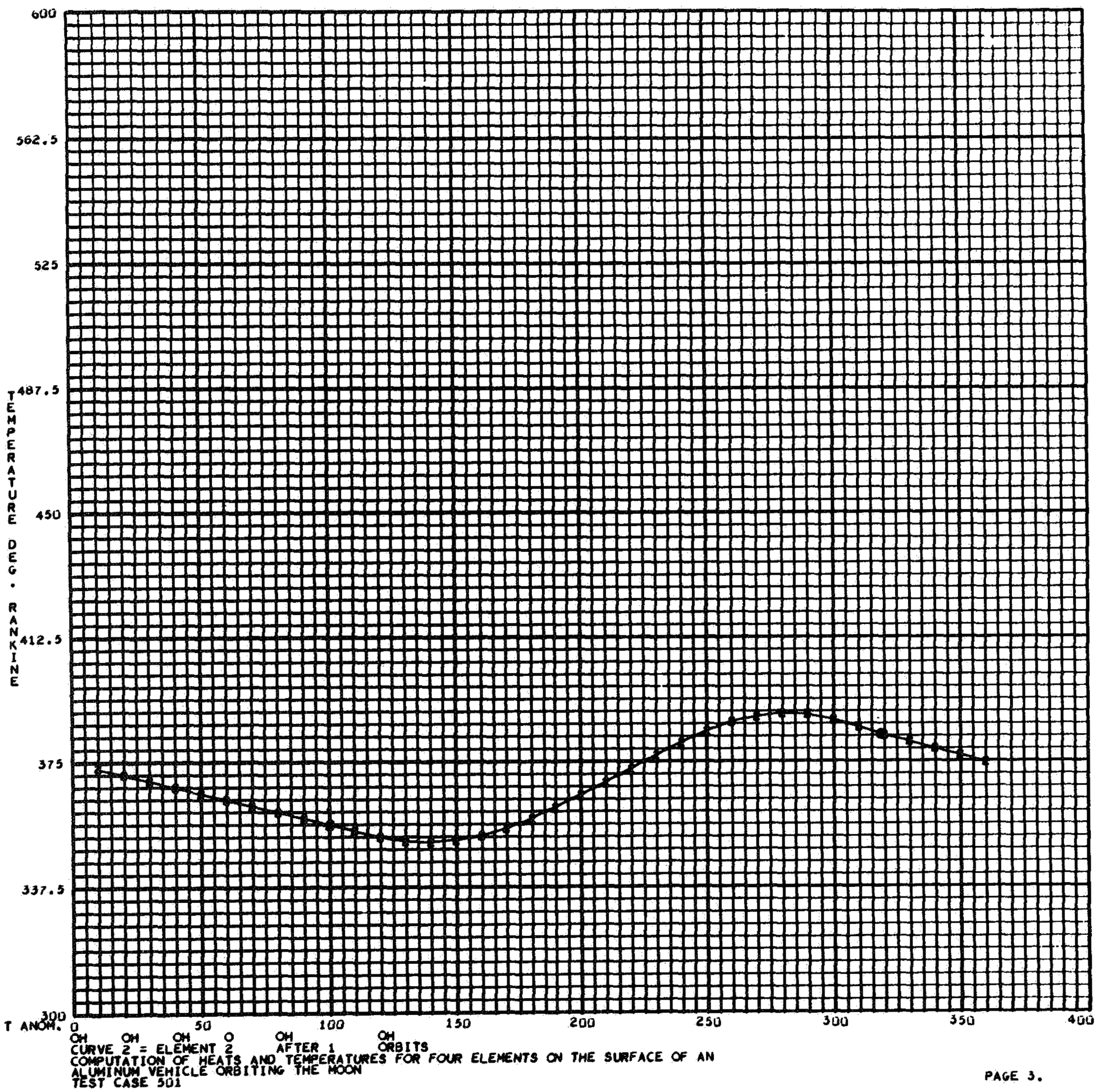
(a) Absorbed heat for node 1.

Figure G-1. - Plotted output from sample case 501.



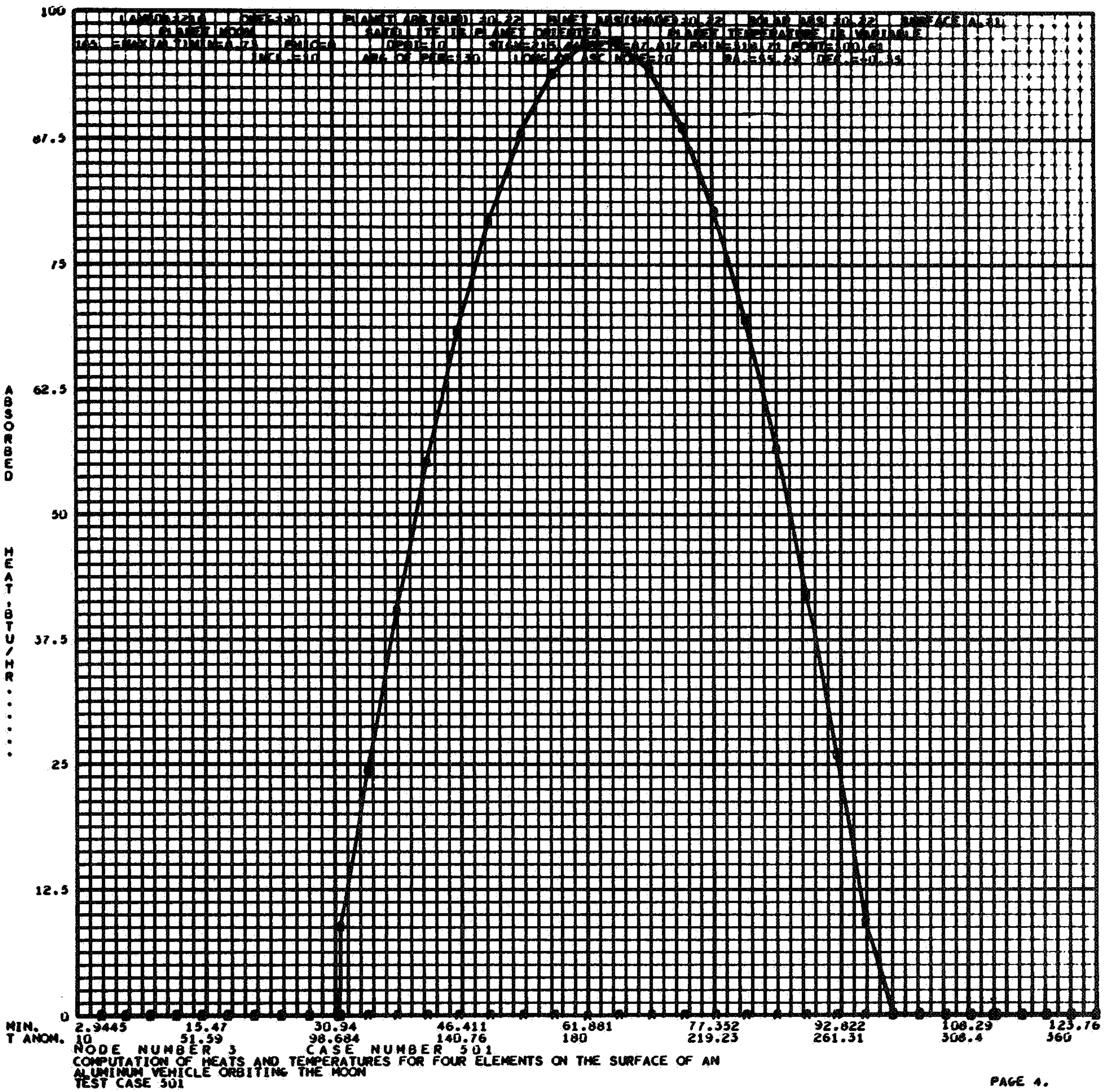
(b) Absorbed heat for node 2.

Figure G-1. - Continued.



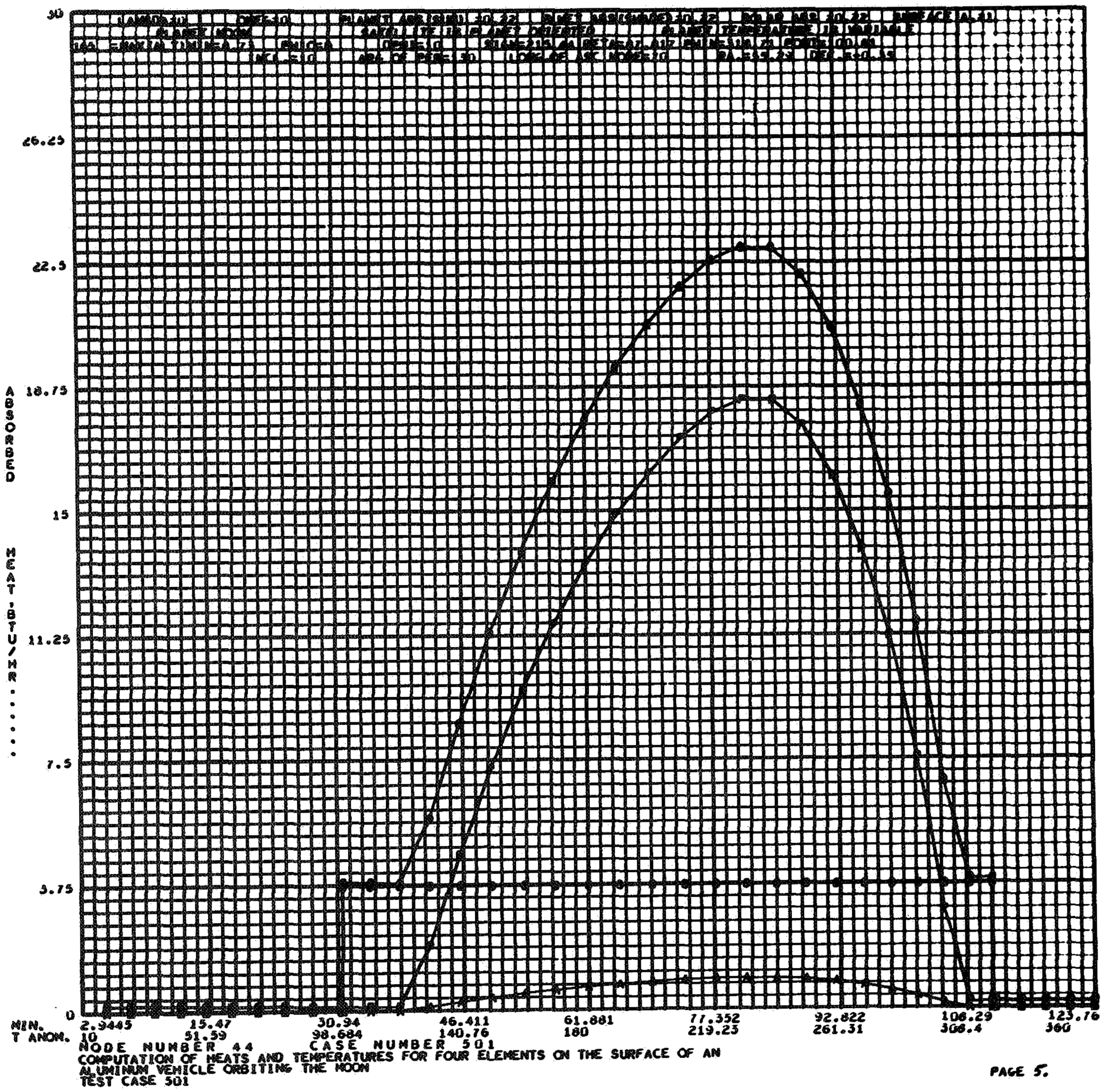
(c) Temperature for node 2.

Figure G-1. - Continued.



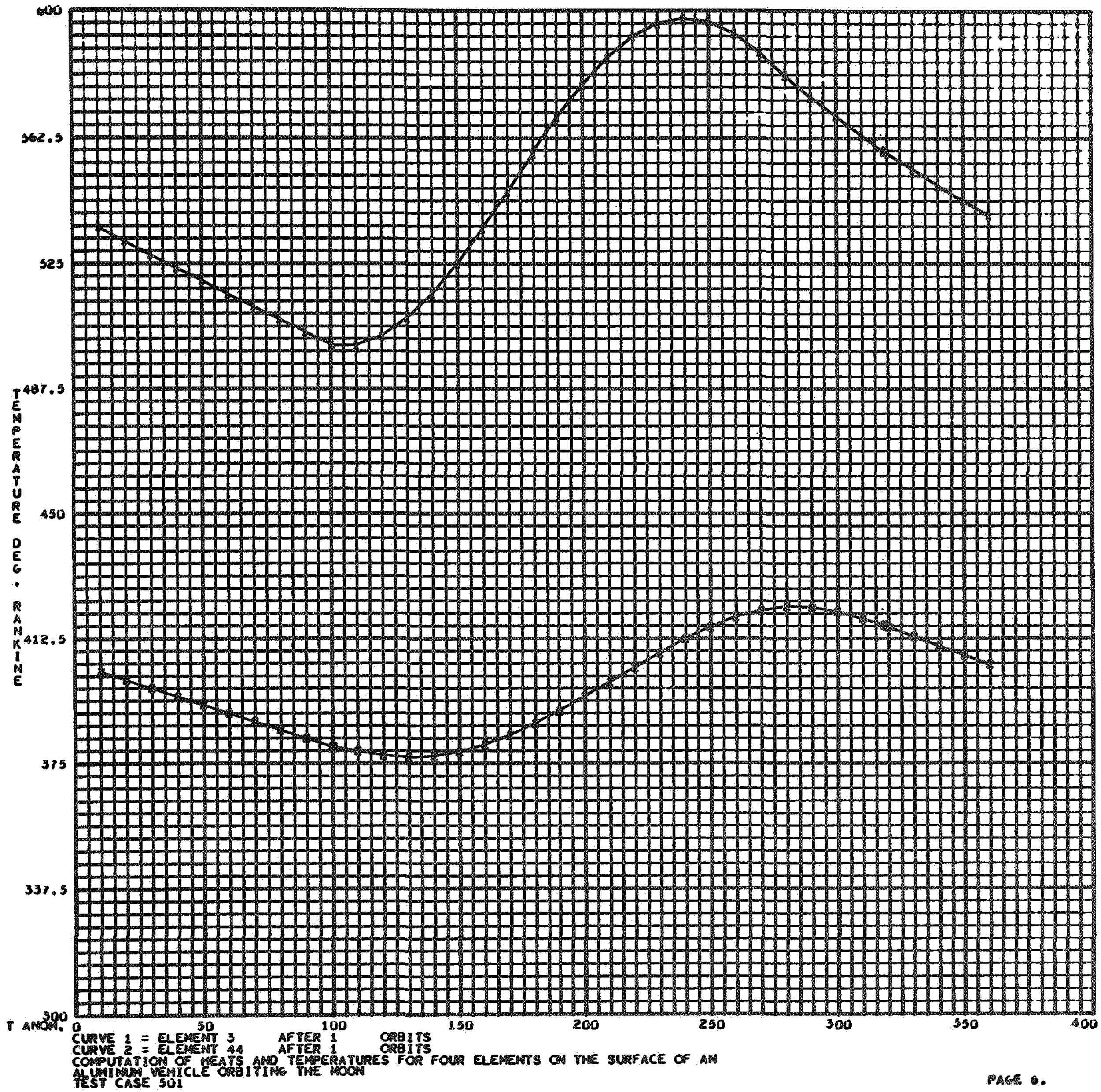
(d) Absorbed heat for node 3.

Figure G-1. - Continued.



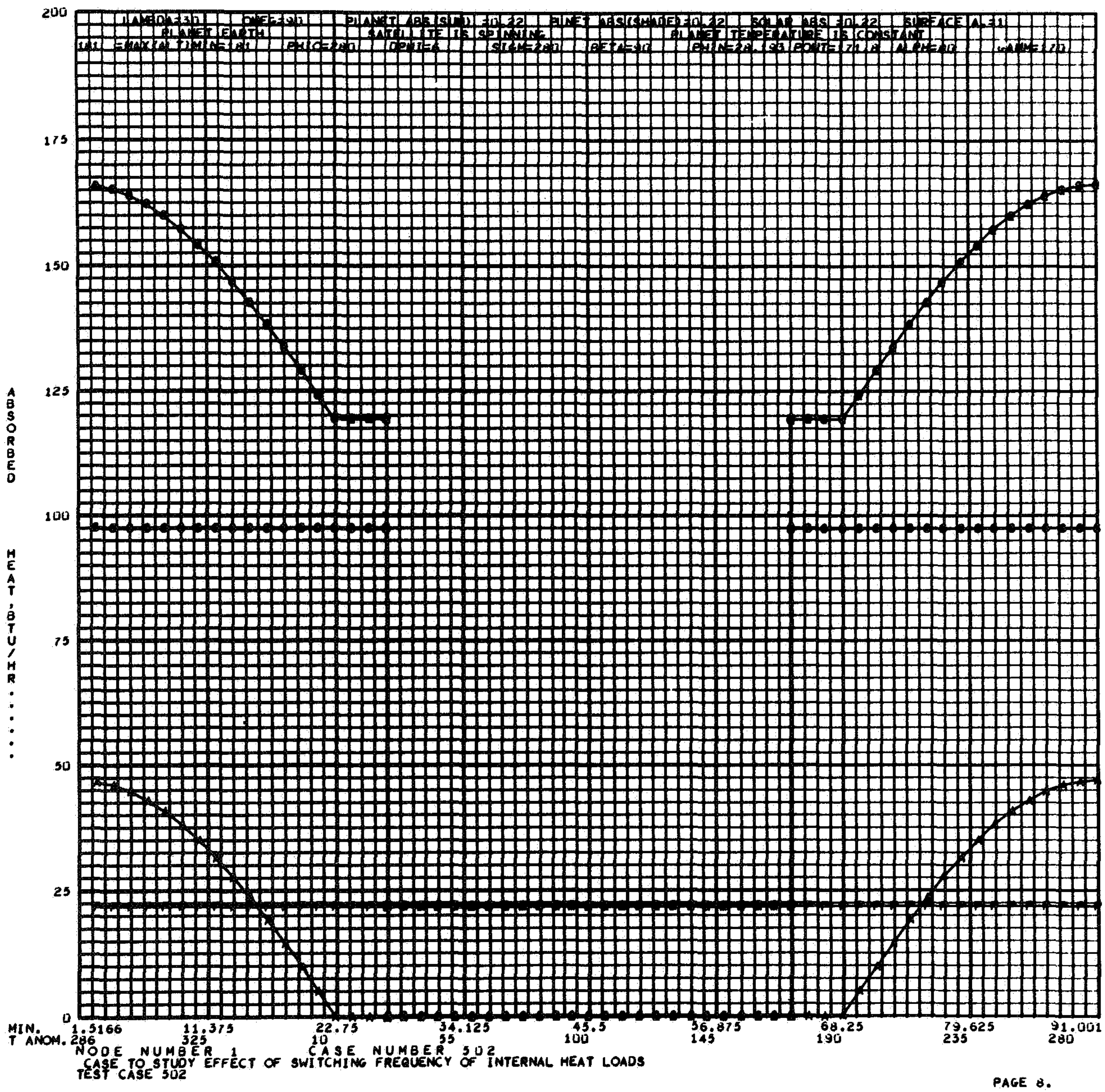
(e) Absorbed heat for node 4.

Figure G-1. - Continued.



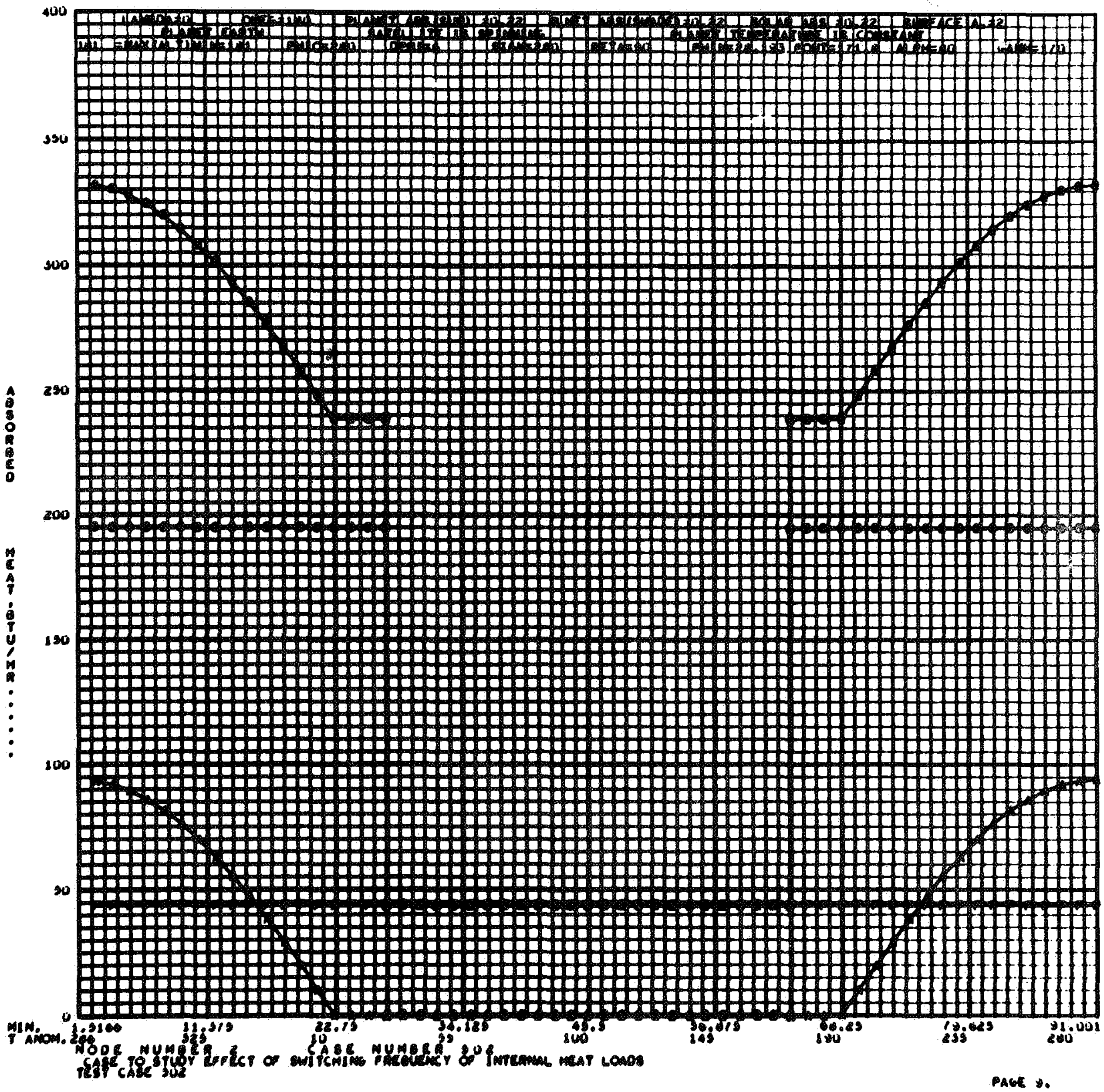
(f) Temperature for nodes 3 and 4.

Figure G-1. - Concluded.



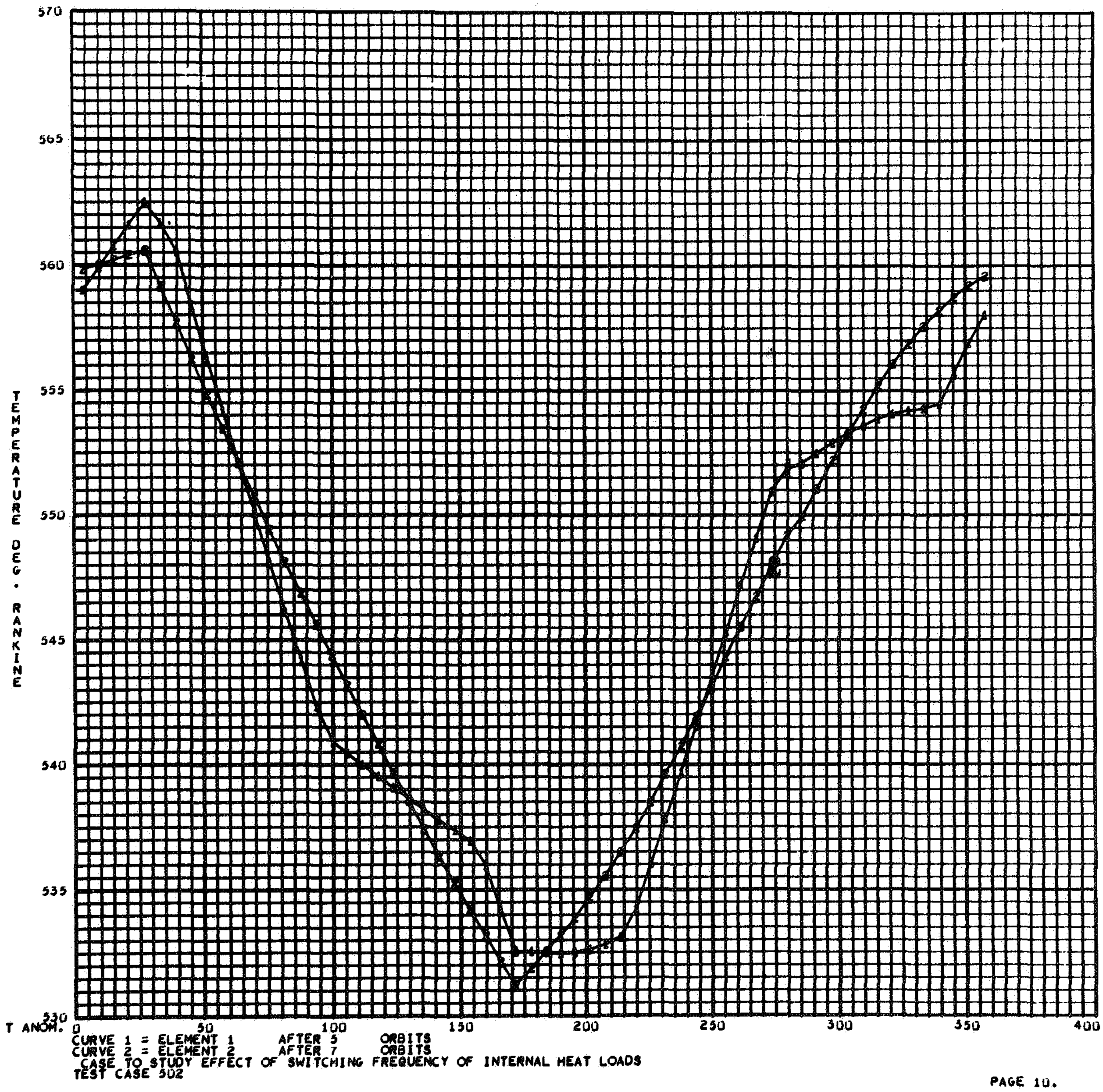
(a) Absorbed heat for node 1.

Figure G-2. - Plotted output from sample case 502.



(b) Absorbed heat for node 2.

Figure G-2. - Continued.



(c) Temperature for nodes 1 and 2.

Figure G-2. - Concluded.

APPENDIX H

OUTPUT PLOT OPTION

The SC-4020 data plotter can be instructed to produce two-dimensional plots and alphanumeric identification of the plots.

Upon request, plots of heat versus time, stabilized temperatures versus true anomaly, or both, are provided. The range for the independent variable is up to and including one complete orbit. The heat plots have a double abscissa scale, with the second scale being true anomaly. Heats can be either incident or absorbed, depending on the input code, with absorbed heat being also a function of input. Generous data identification is provided.

Description of Output

Information is taken from a magnetic tape produced by the program and reproduced visually on 35-mm film by the SC-4020. This film can be used to make enlarged reproductions on sensitized paper. The two types of plots obtainable (heat and stabilized temperature) are discussed separately.

Heat plots. - Plots of incident or absorbed heat versus time are obtained, one element per grid, unless the card type 01 requests temperatures only. The type of heat (albedo, planet, solar, or total) portrayed by each curve can be determined by examining the plotting symbols that correspond to each output point. The following are the symbol conventions:

Plot symbol	Type of heat	Corresponding printout identification
A	Albedo	QALBEDO
P	Planet	QPLAN
S	Solar	QSOLAR
Q	Total (present only on absorbed-heat plots)	QTOTAL

The curves are formed by connecting the points with straight lines. Thus, the smoothness of a curve is a function of the calculation interval.

Some of the parameters used by the program, plus other information, including vehicle-material absorptance with respect to planet-emitted radiation (PLANET ABS) and with respect to solar radiation (SOLAR ABS) are found in the upper portion of the grid.

The planet absorptance has two values, one for the period in which the vehicle is exposed to the Sun and one for the shaded portion of the orbit. When planet temperature is constant, both planet absorptance values, PLANET ABS (SUN) and PLANET ABS (SHADE), are constant throughout the orbit. With variable planet temperature, the PLANET ABS (SHADE) value is constant, but the PLANET ABS (SUN) value is not necessarily constant. If the emittance table used by a particular element is not constant over the entire sunlit effective-planet-temperature range, the PLANET ABS (SUN) value is an average.

Each axis of each plot is numerically labeled at nine locations that do not necessarily correspond to calculation points. The abscissa has two sets of labels, one for elapsed time (minutes) and another for true anomaly (degrees). The true-anomaly values correspond to the time values immediately above. Heat units (Btu/hr or Btu/hr-ft^2) will be printed vertically to the left of the ordinate. Also present will be a notation of whether the heat is absorbed or incident. The element and case numbers are found below the true-anomaly scale.

The remaining portion of the frame will contain as many as three horizontal lines of information. These lines correspond to the first three comment cards (card type 10) physically input in the present case data. These comment cards should be used to identify the plot completely and tie it to the normal output.

Temperature plots. - When temperature calculations are requested by card type 01, plots of stabilized temperature versus true anomaly are obtained. If the temperature of an element has not been stabilized by the end of the last requested orbit, no temperature plot for the element will be given. The program logic determines whether one or two element temperatures will be plotted on a single grid. Each calculation point during the stabilization orbit will be represented on the curve by a numeral one or two. The curves are identified below the grid. As with the heat plots, the smoothness of the curve is a function of the calculation interval.

The vertical axis is numerically labeled with nine values. A vertical alphabetic label is also present. Immediately below the grid is a true-anomaly scale.

The case number, element number, and orbit during which the temperature became stabilized are given for each curve on the grid. Below these items will be the comment-card contents, as on the regular output and heat plots.

Stromberg-Carlson 4020 Data Plotter Requirements

The SC-4020 data plotter is a peripheral system designed to read magnetic-tape output from a digital computer program and to produce graphic and alphanumeric output. As the tape is read, the desired lines and characters are displayed on a cathode-ray tube and exposed to sensitized paper, film, or both. At MSC, the program user receives a strip of developed 35-millimeter negative film that contains the SC-4020 output. This film can then be put on a film viewer, and an enlarged, positive paper copy can be obtained.

When the computer program is run on a Univac 1108 computer at MSC, the routines necessary to generate SC-4020 control instructions are included in the system library. Program users, other than those at MSC, who wish to utilize the plot option must either obtain the routines from MSC or supply a compatible version of their own routines.

APPENDIX I

PROGRAM USER'S GUIDE FOR DATA PREPARATION

The table in this appendix contains detailed information on the preparation of data for the computer program discussed in this report. Throughout this appendix, the DP used in the format listings denote that a decimal point should be used within the specified column; RJ denotes that the data values must be justified on the right side within the specified columns.

MATERIAL-PROPERTIES GROUP

General-Comments Cards

Data-card description:

. The use of the general comments cards is optional. When the card is used, it follows the permanent-data cards.

. Any number of general-comments cards may be used in this location.

. The comments are printed just above the material-properties "echo" check.

Format or columns	Contents	Data comments
1 to 2	10	. The 10 in columns 1 and 2 acts as a flag to the program to signify that general comments follow in columns 3 to 80.
3 to 80	General comments	. Any alphanumeric characters may be used. These columns are usually used for general comments common to the first and any succeeding case.

Material-Properties Table Count Card

Data-card description:

. If comment cards are used, the material-properties table count card will follow. Otherwise, the card follows the permanent-data cards.

. The material-properties table count card is common to the first and any succeeding case.

Material-Properties Table Count Card - Concluded

Format or columns	Contents	Data Comments
2	Number of optical-properties tables	. The total number of optical-properties tables to be loaded is entered in this column. Tables for all cases and not just for the first case must be loaded here, since this is the only place where the program accepts this type of data. . The maximum number of tables allowable is eight.
4	Number of substrate materials	. The total number of substrate materials to be loaded is entered in this column. Tables for all cases and not just for the first case must be loaded here, since this is the only place where the program accepts this type of data. . The maximum number of tables allowable is eight.

Optical-Properties Tables Cards

Data-card description:

. All optical-properties tables are loaded next, one after the other.

. Each table can have no more than seven cards. The desired optical-properties tables for the first and any succeeding cases must be given.

. There is no requirement that all tables loaded must be used.

. Columns 73 to 80 may be used to identify each table.

Format or columns	Contents	Data comments
(6E12. 8)DP	Emittance (infrared absorptance) as a	. Each table consists of alternating temperatures and emittance (infrared absorptance).

Optical-Properties Tables Cards - Concluded

Format or columns	Contents	Data comments
	function of source temperature	. Temperatures are in degrees Rankine.
	Solar absorptance as a constant value	. Each table terminates with the value that follows a temperature of 10 000° R. . The 10 000° R temperature acts as a flag within the program to signal the last pair of data in each table and is therefore required. . The value which follows and corresponds to the 10 000° R temperature, representing the temperature of the Sun, is the place at which the solar absorptance is loaded. Solar absorptance is a single value and cannot vary as a function of temperature.

Substrate-Properties Table Cards

Data-card description:

. The substrate properties must follow the optical-properties tables.

. For each substrate material, a pair of tables must be loaded, one containing specific heat versus temperature, the other density versus temperature.

. Each table can have no more than seven cards.

. Columns 73 to 80 may be used to identify each table.

Substrate-Properties Table Cards - Concluded

Format or columns	Contents	Data comments
(6E12.8)DP	Specific heat as a function of element temperature	. The substrate-properties table consists of alternating temperatures and specific heat. . Temperatures are in degrees Rankine, and specific heat is in Btu/lb. . As in the optical-properties tables, the last pair of data of each table must be flagged with the 10 000° R temperature.
(6E12.8)DP	Density as a function of element temperature	. This table consists of alternating temperatures and density. . Density should be given in lb/ft^3. . The table is loaded in the same manner as the specific-heat table. . For each succeeding substrate material, a specific heat versus temperature table and a density versus temperature table are loaded.

CASE-DATA GROUP

Case-Comments Cards

Data-card description:

. Case-comment cards are optional for each case. If used, they must go at the beginning of the case data.

. Any number of case comment cards may be used in this location.

. All comments are printed on the printout just above the respective case data "echo" check. If a plot routine is used, the first three case comment cards will be printed at the bottom of the respective frames for identification.

Case-Comments Cards - Concluded

Format or columns	Contents	Data comments
1 to 2	10	. The 10 in columns 1 and 2 acts as a flag to the program to signify general comments following in columns 3 to 80.
3 to 80	Case comments	. Any alphanumeric characters may be used. Case comments are usually used for case identification.

GENERAL NOTE PERTAINING TO THE FOLLOWING CASE-DATA CARDS

Except for the last card, the remainder of the data deck is made up of case-data cards, which are differentiated by the card code number appearing in columns 1 and 2. The card code number signifies the card type to the program, which may be numbered from 01 to 07. The card types are shown in numeric order below for convenience; however, there is no required order for card-type groups.

The input requirements have been minimized for parametric type analysis. In running back-to-back cases, the user does not have to load a particular card type, if it is desired to use all of the corresponding data from the preceding case. Therefore, one data card and a blank card to flag end of case may be sufficient data for any case except the first.

Except for a card type 04, the presence of a particular type of case-data card implies that all values normally defined on this card are now to be redefined, using values that follow. However, individual values may be changed or unchanged on the card type 04. If the card type 04, except for the first case, contains a blank in a particular data field, the program will use the corresponding data from the preceding case.

Case-Number and Output-Control Card

Data-card description:

Case-number and output-control card is referred to as card type 01.

Format or columns	Contents	Data comments
1 to 2	01	. The 01 in columns 1 and 2 acts as a flag to the program to signify card type.
4 to 8RJ	Case number	. The case number identifies the case. It is printed out on the printout at the beginning of each case, and if plots are requested it will appear on each corresponding frame. . The case number must be less than 32 768.
10	Output-control code	. The output control applies to the printout and SC-4020 plots. . When SC-4020 plots are requested (nonzero value in column 12 on this card), the only heats plotted will be absorbed heats.
12	SC-4020 plot-control code	. See appendix H for SC-4020 system requirements.

Output-control code (column 10):

Output	Code
Incident heat flux only	0
Temperatures only	1
Incident heat flux and temperature	2
Incident and absorbed heats	3
Incident heat, absorbed heat, and temperature	4

Case-Number and Output-Control Card - Concluded

Format or columns	Contents	Data comments

Output	Code
Plots requested	Nonzero value
No plots	Blank or zero

Print-Control and Angular-Interval Card

Data-card description:

. The print-control and angular-interval card is referred to as card type 02.

Format or columns	Contents	Data comments
1 to 2	02	. The 02 in columns 1 and 2 acts as a flag to the program as to signify card type.
3 to 4RJ	Print-control code (NPRINT)	. Blanks or a 1 cause printout after each interval. Otherwise, the program prints only after NPRINT intervals.

Print frequency	Code
Every compute interval	Blank, zero, or 1
Every NPRINT compute interval	Value of NPRINT

Print-Control and Angular-Interval Card - Concluded

Format or columns	Contents	Data comments
6 to 8RJ	Printout format control	. With columnar format, the results are all printed out in columns.
	Type — Code	. The block format prints the results in rows; this generally takes less printout paper, but makes results more difficult to analyze.
	Columnar — $\neq 359$	
	Block — 359	. Block output cannot be requested when absorbed heats are called for; that is, when column 10 of the card type 01 has a 3 or 4.
11 to 18DP	Initial true anomaly ϕ_o	. Vehicle position at time zero is specified in degrees of arc.
19 to 26DP	Compute interval $\Delta\phi$	. This is the increment in true anomaly which specifies the frequency of calculations. The basic angular interval $\Delta\phi$ should be a submultiple of 360; that is, 2, 5, 6, 7.5, 8, 9, 10 are suitable values but 7 is not, since 360/7 is not an integer.
		. If SC-4020 plots are requested (card type 01 column 12), $\Delta\phi$ must be $\geq 2^\circ$.
		. Care should be given to the choice of $\Delta\phi$, since all computed values are assumed constant over the interval unless the vehicle enters or leaves the planet shadow. From experience, a $\Delta\phi$ of 5° is generally acceptable.
27 to 34DP	Number of orbits	. The number of orbits or fractions of orbits that the vehicle is to make around the planet are specified.

Planet, Orbit, and Vehicle Attitude Card

Data-card description:

. The planet, orbit, and vehicle-attitude card is referred to as card type 03.

Format or columns	Contents	Data comments
1 to 2	03	. The 03 in columns 1 and 2 acts as a flag to the program to signify card type.
4	Planet code	. The planet to be orbited is called out by the corresponding code.

Planet	Code
Earth	1
Moon	2
Jupiter	3
Mars	4
Mercury	5
Neptune	6
Saturn	7
Uranus	8
Venus	9

Planet, Orbit, and Vehicle Attitude Card - Concluded

Format or columns	Contents	Data comments
5 to 6RJ	Vehicle-attitude code Attitude / Code Spinning: Blank or zero Planet oriented: 1 Sun oriented: -1	. For definition of a spinning, planet-oriented, or Sun-oriented vehicle, see the section of this report entitled "Heat-Transfer Theory." The method and equations used internally for each of these cases are also given in this section.
8	Constant or variable planet-temperature code Temperature / Code Constant: Blank or zero Variable: 1	. The method and equations for handling a constant or variable planet temperature are given in the section of this report entitled "Heat-Transfer Theory." . Constant planet temperature must be used for all celestial bodies except the Moon. The program sets the planet temperature code to zero (constant temperature) whenever any planet code except 2 is used in column 4.
51 to 65DP	Maximum orbit altitude (n. mi.)	
66 to 80DP	Minimum orbit altitude (n. mi.)	

Element-Data Card

Data-card description:

. The element-data card is referred to as card type 04.

. If it is desired to change information pertaining to a particular element (or elements) in a succeeding case, cards type 04 need not be reinput for all elements. For example, if in case 1 there are three elements and if in case 2 it is desired to change only the skin thickness of element 2, it is necessary only to input a card type 04 containing a 2 in column 6 and the new thickness in columns 35 to 42. A blank card would also have to be present to signify end of case input.

Format or columns	Contents	Data comments
1 to 2	04	. The 04 in columns 1 and 2 acts as a flag to the program to signify card type.
4 to 6RJ	Element-number identification	. The element numbers for a particular case must be consecutive from one to NSATP (maximum = 200). NSATP is defined by card type 07 as the total number of elements present (that is, 1, 2, 3, 4, . . . NSATP). Although the elements must be numbered consecutively, they can be arranged in any order (that is, 1, 3, 2, NSATP, . . . 4).
8	Optical-properties table number	. This is the optical-properties table number for the element being described. The first optical-properties table loaded is optical-properties table number 1, et cetera. . The number may be from 1 to 8.
9	Substrate-properties table number	. This is the number of the substrate-properties table for the element being described. The first substrate material loaded is substrate-properties table number 1, and so forth. . The number may be from 1 to 8. . This input is not required when temperature calculations are not requested.

Element Data Card - Continued

Format or columns	Contents	Data comments
10	Internal-heat table number	. This is the number of the internal-heat table, loaded on card type 06, for the element being described. . The number may be from 1 to 8. . This input is not required when temperature calculations are not requested.
11 to 18DP	Λ'	. The symbol Λ' is defined as the angle measured from the X_v-axis $(\text{toward } Y_v)$ to the projection of the line connecting the center of the vehicle coordinate system and the element (referred to as the vehicle-vehicle element line) on the X_v-Y_v plane. . The symbol Λ' is given in degrees of arc, which may vary from 0° to 360°. . Another angle is needed to locate the element; this is Ω' and is defined in the next data field. . For a description of the vehicle coordinate system, refer to table D-I and the section of this report entitled "Celestial Mechanics Theory: Coordinate Systems."
19 to 26DP	Ω'	. The symbol Ω' is defined as the angle measured from the Z_v-axis to the vehicle-vehicle element line. . The symbol Ω' is given in degrees of arc, which may vary from 0° to 180°. . Note that if vehicle orientation or attitude is changed from the preceding case, it is necessary that Λ' and Ω' be determined again, since the vehicle axes change.

Element Data Card - Concluded

Format or columns	Contents	Data comments
27 to 34DP	Initial element temperature (°R)	. This value is not required when temperature calculations are not requested.
35 to 42DP	Element skin thickness (ft)	. This value is not required when temperature calculations are not requested.
43 to 48DP	Element surface area (ft^2)	. The loading of area is only applicable when absorbed heats are requested (*card type 01*). . Either all or none of the elements in a particular case may have an area input. Such an input causes the absorbed heat to be a rate (Btu/hr) rather than a flux (Btu/hr-ft^2).
51 to 56DP	Node number	. Each element may have an equivalent node number from 1 to 999. *When a node number is loaded for a particular* element, the program will then identify the respective answers by the node number and not element number. . If a node number is not given to a particular element, the respective answers will be identified by the element number. . The node number must have a decimal point.

Sun-Position Card

Data-card description:

. The Sun-position card is referred to as card type 05.

Format or columns	Contents	Data comments
1 to 2	05	. The 05 in columns 1 and 2 acts as a flag to the program to signify card type.
3 to 4RJ	Type of data for Sun position Data type — Code Read in α, β, γ data — 3 Read in ephemeris data — $\neq 3$	. The code is used to signal what type of data is to be used to describe Sun position. . If the Sun position is to be read in terms of angles α, β, and γ, a 3 must be punched in column 4. Sun position is then expressed directly with respect to the planet coordinate X_p-, Z_p-, and Y_p-axes in terms of α, β, and γ, respectively, as shown in figure 9. The planet coordinate system is summarized in table D-I. . If Sun position is taken from an ephemeris, a blank or any number other than 3 in column 4 will mean that instead of α, β, and γ being read in, i, ω, Ω, RA, and DEC will be read in. . Refer to the section of this report entitled "Celestial Mechanics Theory: Coordinate Systems" for definition of those angles required as input for the ephemeris data input option. . Sample calculations for obtaining RA and DEC of the Sun from an ephemeris are shown in appendix D.

Sun-Position Card - Continued

Format or columns	Contents	Data comments
6	Compute Sun shade point code Option / Code Compute ϕ_{in} and ϕ_{out} / Zero or blank Input ϕ_{in} and ϕ_{out} / 1	. The points ϕ_{in} and ϕ_{out}, at which the vehicle passes in and out of the planet shadow, are normally computed from orbit geometry and Sun position. However, they may be read in if desired. This feature was provided principally as a debugging aid, but could conceivably be used in other ways.
11 to 18DP	Orbit inclination i, or α	. Load the angle of inclination i unless column 4 contains a 3, in which case, angle α is entered. . Both angles are in degrees of arc. . The angle of inclination i is the true inclination between the X_c-Y_c plane and the orbital plane. . The value of i is always $\leq 90°$. . The angle between the planet-Sun line and the X_p-axis is α. . The value of α is always $\leq 180°$.
19 to 26DP	Argument of perifocus ω, or β	. Load ω, the argument of perifocus unless column 4 contains a 3, in which case, angle β is entered. . Both angles are in degrees of arc.

Sun-Position Card - Continued

Format or columns	Contents	Data comments
		. The argument of perifocus ω is measured in the orbital plane, in the direction of travel from the right ascension of the ascending node to the perifocus. The vehicle direction of travel is always in the same direction as when the X_p-axis is rotated in the orbital plane towards Y_p through the smallest angle.
		. The value of ω is always $\leq 360°$.
		. The angle between the planet-Sun line and the Z_p-axis is β.
		. The value of β is always $\leq 180°$.
27 to 34DP	Longitude Ω of the ascending node, or γ	. Load Ω, longitude of the ascending node, unless column 4 contains a 3, in which case, angle γ is entered.
		. Both angles are in degrees of arc.
		. The longitude Ω of the ascending node is measured counterclockwise in the X_c-Y_c plane from X_c to the line of nodes.
		. The value of Ω is always $\leq 360°$.
		. The angle between the planet-Sun line and the Y_p-axis is γ.
		. The value of γ is always $\leq 180°$.
35 to 42DP	Right ascension RA of the Sun	. Load RA of the Sun, unless column 4 contains a 3, in which case, the columns are ignored.
		. The right ascension should be given in degrees of arc.

Sun-Position Card - Concluded

Format or columns	Contents	Data comments
		. The RA is obtained from the ephemeris. See appendix D, which gives sample data preparation for RA and DEC of the Sun.
45 to 50DP	Declination DEC of the Sun	. Load DEC, declination of Sun, unless column 4 contains a 3, in which case, the columns are ignored. . The DEC should be given in degrees of arc. . The DEC is also obtained from the ephemeris.
51 to 65DP	True anomaly ϕ_{in} at which vehicle enters planet shadow	. The program ignores this value unless a 1 is punched in column 6.
66 to 80DP	True anomaly ϕ_{out} at which vehicle leaves planet shadow	. The program ignores this value unless a 1 is punched in column 6.

Internal-Heat Table Cards

Data-card description:

. The internal-heat table cards are referred to as card type 06.

. Cards type 06 are optional and may be omitted entirely. An undefined heat table is assumed to contain no heat loads. Once a particular heat table is defined, it remains unchanged until another card type 06 redefines heat load for that table.

. Each internal-heat table is loaded as step functions. The heat load is considered constant over a period of time, until a new switching time is given with a new constant heat-load value.

Internal-Heat Table Cards - Continued

. If the table contains switching times that are greater than the orbital period, those switching times are ignored, since the program resets the internal-heat tables to time zero at the end of each orbit.

Format or columns	Contents	Data comments
1 to 2	06	. The 06 in columns 1 and 2 acts as a flag to the program to signify card type.
4	Internal-heat table number	. This is the number of the internal-heat table being read in. . The program user may load in up to eight such tables.
5 to 6RJ	Number of heat values in table	. If greater than zero, this is the number of internal-heat values other than the starting value to be read into this table. . This number may be from 1 to 19. . To define or redefine an internal-heat-table so that it has no heat loads, blanks or zeros are punched in columns 5 and 6. . If the heat load is constant at some value other than zero, a 1 must be punched in column 6. Then columns 11 to 18 should contain the constant heat load, and columns 19 to 26 should contain a very large number such as 90 000, corresponding to the time switching occurs. An example of constant heat table is given in case 502 of the sample data deck (appendix G).
11 to 18DP	$Q_g(0)$, initial heat load for table indicated in column 4 (Btu/hr-ft^2)	
19 to 26DP	t_1, time at which the first change of heat	

Internal-Heat Table Cards - Concluded

Format or columns	Contents	Data comments
	load in this table will occur (min)	
27 to 34DP	$Q_g(t_1)$, heat-load value from t_1 (Btu/hr-ft^2)	
35 to 42DP	t_2, time at which the second change of heat load in this table will occur (min)	
43 to 50DP	$Q_g(t_2)$, heat-load value from t_2 (Btu/hr-ft^2)	
51 to 65DP	t_3, time at which the third change of heat load in this table will occur (min)	
66 to 80DP	$Q_g(t_3)$, heat load value from t_3 (Btu/hr-ft^2)	

Continuation cards for internal heat

If columns 5 and 6 contain a number from 4 to 19, then from one to four continuation cards are necessary. Continuation cards must follow immediately after the card type 06 that they complete and must be in chronological order. The format for continuation cards is exactly as described previously, except the first switching time of each continuation card is punched in columns 3 to 10, with a decimal point. Heat loads after switching are punched following corresponding switching times until all heat loads that were specified in columns 5 and 6 of the first card type 06 have been punched. An example of card type 06 continuation cards is given in case 502 of the sample data deck in appendix G.

Element Count Card

Data-card description:

. The element count card is referred to as card type 07.

Format or columns	Contents	Data comments
1 to 2	07	. The 07 in columns 1 and 2 acts as a flag to the program to signify card type.
4 to 6RJ	Total number of vehicle elements (NSATP)	. This must be the same as the total number of cards type 04. . The maximum allowable number of elements is 200.

End of Case Card

Data-card description:

Format or columns	Contents	Data comments
1 to 80	Blank	. Each case, including the first case, always ends with a a blank card.

APPENDIX J

PROGRAM LISTING

```
$JOB   F40P    PARKER      005258 ED241 F007  3550F P 010 010          4020
*       ASG        A=NEWPCF
*       FOR        EXEC,EXEC
CMAIN PROGRAM (CALLED PILOT)
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),
     2GAMM(200),NDUTY(200)
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)
      DIMENSION BUFFER(3)
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN
      COMMON TIMEZ,TABS,IELAPS,ZEIT,TIME,DELTAT,XP,YP,DFE,DPSQ,J1,J2
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF
      COMMON PHI1,PHI2,ISIG,FUDGE,T4 ,BUFFER,RV,NLINE
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,
     1COSRS,PHIT,GAMM
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,
     1DECLIN
      DIMENSION AA(6),AA1(6),P(6),P1(6)
      COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,
     1YNHAT,ENHATL,EMAG,DERROR,DTTEST
      COMMON HSUN,HALB,HPLAN,NODE
      DIMENSION HSUN(200),HALB(200),HPLAN(200),NODE(200)
      COMMON KETCH
      COMMON HASUN,HAALB,HAPLN,HATOT
      DIMENSION HASUN(200),HAALB(200),HAPLN(200),HATOT(200)
      COMMON ZAREA
      DIMENSION ZAREA(200)
      COMMON IMTHRU
      DIMENSION IMTHRU(200)
      COMMON IMHI,PNAME,PHIPLT,TIMPLT,NPLOT,LAST,JUMP,LMAX,IONCE
      DIMENSION PNAME(39),PHIPLT(190),TIMPLT(190)
      COMMON TYME1,TYME2,TYME
      COMMON/BK1K/JIJK
C ***      SCRATCH TAPES UTILIZED BY LINK 1 ARE., 4,9 AND 11
C ***      SCRATCH TAPES UTILIZED BY LINK 2 ARE 9 AND 11
C*************************************************************************
C ***      OUTPUT TAPE IS 6, INPUT IS 5
C*************************************************************************
C
C
      IONCE=0
  255 JIJK=0
      IF(IONCE-1)2,1,2
    2 JUMP=1
      IONCE=1
      NPLOT=0
    1 IF(NPLOT)4,5,4
    4 TYME=TYME1+TYME2
      WRITE (6,9999)TYME1,TYME2,TYME
```

```
 9999 FORMAT( /// 18H CALCULATION TIME=F6.2,13H , PLOT TIME=F6.2,         EXEC0580
     1 28H , TOTAL TIME FOR THIS CASE=F6.2,30H...ALL TIMES ARE IN MINUTEEXEC0590
     2S...    )                                                          EXEC0600
    5 CONTINUE                                                           EXEC0610
C *** JUMP=2 MEANS WE HAVE RETURNED FROM LINK 2 (PLOT ROUTINES)           EXEC0620
      GO TO (3,290),JUMP                                                 EXEC0630
C                 CONSTANTS FOR NUMERICAL INTEGRATION                    EXEC0640
    3 IORDER=4                                                           EXEC0650
      FACT=1.0/(1.0-0.5**IORDER)                                         EXEC0660
      AA(1)=1.0/6.0                                                      EXEC0670
      AA(4)=AA(1)                                                        EXEC0680
      AA(2)=AA(1)*2.0                                                    EXEC0690
      AA(3)=AA(2)                                                        EXEC0700
      P(1)=0.0                                                           EXEC0710
      P(2)=.5                                                            EXEC0720
      P(3)=0.5                                                           EXEC0730
      P(4)=1.0                                                           EXEC0740
      IORD1=1                                                            EXEC0750
      IFIRST=1                                                           EXEC0760
C     CALL ROUTINE TO READ IN DATA AND PRINT HEADING                     EXEC0770
  290 CALL TINPUT                                                        EXEC0780
      IERROR=3                                                           EXEC0790
      IF(FUDGE+2669.0) 2669,2668,2669                                    EXEC0800
 2668 IERROR=1                                                           EXEC0810
 2669 EN=0.0                                                             EXEC0820
      EMAG=0.0                                                           EXEC0830
      ENHATL=0.0                                                         EXEC0840
      YNHAT=0.0                                                          EXEC0850
C               CONSTANTS FOR DIFFERENTIAL EQUATION                      EXEC0860
      SAS2=0.5*S                                                         EXEC0870
      SRASH=SAS2*R                                                       EXEC0880
      EPTP4=0.5*(1.0-R)*S                                                EXEC0890
      T4=SQRT(SQRT(S*(1.0-R)/6.856E-09))                                 EXEC0900
C               SET ALTERNATING INDICES                                  EXEC0910
  150 J1=1                                                               EXEC0920
      J2=2                                                               EXEC0930
      TIME(1)=0.0                                                        EXEC0940
C     CALL ROUTINE TO MOVE VEHICLE ALONG ITS PRESCRIBED ORBIT AND        EXEC0950
C                         PERFORM REQUIRED CALCULATION                   EXEC0960
      CALL LOOP                                                          EXEC0970
      IF(JIJK.NE.0)GO TO 255                                             EXEC0980
      GO TO 290                                                          EXEC0990
      END                                                                EXEC1000


*      FOR      DECK1,DECK1                                              DK010000
      SUBROUTINE HEAD                                                    DK010010
C                PRINT OUT CAPTION PAGE                                  DK010020
      WRITE (6,1)                                                        DK010030
    1 FORMAT(1H1////////////////)                                        DK010040
      WRITE (6,2)                                                        DK010050
  2   FORMAT(40X,51HA COMPUTER PROGRAM FOR CALCULATING EXTERNAL THERMAL/DK010060
     140X,        51HRADIATION HEAT LOADS AND TEMPERATURES OF SPACECRAFT/DK010070
     246X,        38HORBITING ABOUT THE PLANETS OR THE MOON             DK010080
     3////                                                               DK010090
     464X,2HBY // 42X,47HMIDWEST RESEARCH INSTITUTE,KANSAS CITY,MISSOURIDK010100
     5/63X,3HAND /44X,43HNASA MANNED SPACECRAFT CENTER,HOUSTON,TEXAS    DK010110
     6/////////////// 42X,52HDOCUMENTED IN THE NASA TECHNICAL REPORT  TRDK010120
     7-R(S97)  /44X,43HBY H.FINCH,R.VOGT,D.SOMMERVILLE,AND D.BLAND      )DK010130
      WRITE (6,611)                                                      DK010140
```

```
611   FORMAT(1H1)                                                       DK010150
      CALL FREAD                                                        DK010160
      RETURN                                                            DK010170
      END                                                               DK010180


       FOR      DECK2,DECK2                                             DK020000
      SUBROUTINE TINPUT                                                 DK020010
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),   DK020020
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                   DK020030
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),       DK020040
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),  DK020050
     2GAMM(200),NDUTY(200)                                              DK020060
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)         DK020070
      DIMENSION BUFFER(2)                                               DK020080
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,    DK020090
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                            DK020100
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV      DK020110
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,    DK020120
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                    DK020130
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                 DK020140
      COMMON PHIZ2,DPHIZ2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN       DK020150
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2    DK020160
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH                             DK020170
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                             DK020180
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK       DK020190
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                         DK020200
      COMMON PHI1,PHI2,ISIG,FUDGE,T4,JUDGE,BUFFER,RV,NLINE              DK020210
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,    DK020220
     1COSRS,PHIT,GAMM                                                   DK020230
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,    DK020240
     1DECLIN                                                            DK020250
      DIMENSION AA(6),AA1(6),P(6),P1(6)                                 DK020260
      COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,   DK020270
     1YNHAT,ENHATL,EMAG,DERROR,DTTEST                                   DK020280
      COMMON HSUN,HALB,HPLAN,NODE                                       DK020290
      DIMENSION HSUN(200),HALB(200),HPLAN(200),NODE(200)                DK020300
      COMMON KETCH                                                      DK020310
      COMMON HASUN,HAALB,HAPLN,HATOT                                    DK020320
      DIMENSION HASUN(200),HAALB(200),HAPLN(200),HATOT(200)             DK020330
      COMMON ZAREA                                                      DK020340
      DIMENSION ZAREA(200)                                              DK020350
      COMMON IMTHRU                                                     DK020360
      DIMENSION IMTHRU(200)                                             DK020370
      COMMON IMHI,PNAME,PHIPLT,TIMPLT,NPLOT,LAST,JUMP,LMAX,IONCE        DK020380
      DIMENSION PNAME(39),PHIPLT(190),TIMPLT(190)                       DK020390
      EQUIVALENCE(TRASH(15),C1),(TRASH(16),C2),(TRASH(17),C3)           DK020400
      DIMENSION W(7),Z(41),NZ(41)                                       DK020410
      EQUIVALENCE(TRASH(14),NBLANK),(Z(1),NZ(1))                        DK020420
      DIMENSION TZ(200)                                                 DK020430
      DIMENSION ELAMB(200),OMEGA(200)                                   DK020440
      DIMENSION TKALT(9)                                                DK020450
      COMMON TYME1,TYME2,TYME                                           DK020460
      COMMON AG,      IN,J,KABG,KL,       K,LPJ,LL,LN,L,LSHADF,M,NCARD, DK020470
     1NEWDC,NEWGAM,NEWMAT,NHEAD,N,NTRIG,PFE1,PG,PIN,POUT,ROP,SIGMA2     DK020480
      COMMON ELAMB,OMEGA,TKALT,TZ,W ,AGNM,PGNM                          DK020490
C *** THE PURPOSE OF THE LAST 3 STATEMENTS (COMMON AG THRU PGNM )       DK020500
C      IS TO PRESERVE VALUES ESTABLISHED IN TINPUT. THIS  COMMON        DK020510
C      (AND ASSOCIATED DIMENSION STATEMENTS) ALSO APPEARS IN THE        DK020520
C      MAIN PROGRAM OF LINK 2 .                                         DK020530
```

```
      EQUIVALENCE (NAREA,AREA)                                          DK020540
      NHEAD=1                                                           DK020550
      JFLAG=0                                                           DK020560
      DO 1005 IBL=1,39                                                  DK020570
      DATA Q000CT/0050505050505/                                        DK020580
 1005 PNAME(IBL)=Q000CT                                                 DK020590
      LN=0                                                              DK020600
      DO 392 I=1,NSATP                                                  DK020610
  392 IMTHRU(I)=0                                                       DK020620
      REWIND 4                                                          DK020630
      REWIND 9                                                          DK020640
      REWIND 11                                                         DK020650
      NEWGAM=0                                                          DK020660
      NEWDC=0                                                           DK020670
      NEWMAT=0                                                          DK020680
      IF(IFIRST-1) 51,39,39                                             DK020690
C          THIS SEQUENCE IS EXECUTED ONLY ONCE                          DK020700
 39   IFIRST=0                                                          DK020710
      KETCH=0                                                           DK020720
      CALL HEAD                                                         DK020730
C     SET PLANET COLD SIDE TEMPERATURES                                 DK020740
      DO 391 J=3,8                                                      DK020750
 391  TKALT(J)=50.0                                                     DK020760
      TKALT(2)=186.0                                                    DK020770
      TKALT(5)=10.0                                                     DK020780
      TKALT(1)=200.0                                                    DK020790
      TKALT(4)=200.0                                                    DK020800
      TKALT(9)=200.0                                                    DK020810
C             READ COMMENT CARDS                                        DK020820
C                  NCARD GREATER THAN 9 INDICATES COMMENT CARD          DK020830
C **** TAPE 3 WAS REPLACED BY TAPE 9 TO ACCOMMODATE THE CHAINED PROGRAMSDK020840
C **** NECESSARY FOR PLOT OPTION.  (SEPT. 14,1964)                      DK020850
C     COMMENTS ARE STORED ON TAPE 9 TO BE COPIED AFTER HEADING IS WRITTENDK020860
   51 READ(5,6042) K,(Z(J),J=1,13)                                      DK020870
 6042 FORMAT(I2,13A6)                                                   DK020880
      IF(K)51,51,570                                                    DK020890
 570  IF(K-8) 6041,572,572                                              DK020900
 572  WRITE (9,6042)K,(Z(J),J=1,13)                                     DK020910
      IF(NHEAD-3)10000,10000,10001                                      DK020920
10000 DO 10002 LBJ=1,13                                                 DK020930
      IN=LN+LBJ                                                         DK020940
10002 PNAME(IN)=Z(LBJ)                                                  DK020950
      NHEAD=NHEAD+1                                                     DK020960
      LN=LN+13                                                          DK020970
10001 CONTINUE                                                          DK020980
      GO TO 51                                                          DK020990
 6041 JFLAG=1                                                           DK021000
      GO TO 52                                                          DK021010
C             BRANCH TO STORE INPUT DATA                                DK021020
 604  GO TO 605                                                         DK021030
 605  GO TO (1,2,3,4,5,6,7),NCARD                                       DK021040
 1    NUMRUN=(100*K+L)*100+M                                            DK021050
      NQORT=N                                                           DK021060
      NPLOT=W(1)                                                        DK021070
      GO TO 52                                                          DK021080
 2    NPRINT=MAX0(K,1)                                                  DK021090
      JUDGE=100*L+M                                                     DK021100
      PHIZZ=W(1)                                                        DK021110
      DPHIZ=W(2)                                                        DK021120
      REV=W(3)                                                          DK021130
```

```
      PHIZ=PHIZ2*PI180                                                  DK021140
      DPHI=DPHI2*PI180                                                  DK021150
C              READ CASE DATA                                           DK021160
   52 IF(JFLAG) 934,935,934                                             DK021170
  934 READ(30,600) NCARD,K,L,M,N,(W(J),J=1,7)                           DK021180
      JFLAG=0                                                           DK021190
      GO TO 936                                                         DK021200
  935 READ(5,600) NCARD,K,L,M,N,(W(J),J=1,7)                            DK021210
  936 CONTINUE                                                          DK021220
 600  FORMAT(5I2,5F8.2,2E15.7)                                          DK021230
      IF(NCARD) 99,99,604                                               DK021240
 3    KPLNET=MAX0(K,1)                                                  DK021250
C DO NOT PERMIT VARIABLE TEMPERATURES EXCEPT FOR THE MOON               DK021260
      IF(KPLNET-2)2000,2005,2000                                        DK021270
 2000 M=0                                                               DK021280
 2005 CONTINUE                                                          DK021290
      NORIEN=L                                                          DK021300
      KTEMP=M                                                           DK021310
      TM=TKALT(K)                                                       DK021320
      FUDGE=W(1)                                                        DK021330
      ROP=RPP(KPLNET)                                                   DK021340
      AG= W(6)*6076.1033                                                DK021350
      PG= W(7)*6076.1033                                                DK021360
      AGNM=W(6)                                                         DK021370
      PGNM=W(7)                                                         DK021380
      IF(AG-PG) 450,451,452                                             DK021390
  450 AG=W(7)  *6076.1033                                               DK021400
      PG=W(6) *6076.1033                                                DK021410
      AGNM=W(7)                                                         DK021420
      PGNM=W(6)                                                         DK021430
      WRITE (6,453)                                                     DK021440
  453 FORMAT (// 89H YOU INPUT AN ORBIT ALTITUDE MAX. LESS THAN THE MIN.DK021450
     1..I REVERSED THEM AND SHALL CONTINUE. //)                         DK021460
      GO TO 452                                                         DK021470
  451 A= AG + ROP                                                       DK021480
      B= A                                                              DK021490
      C=SQRT(A*A -B*B)                                                  DK021500
      GO TO 460                                                         DK021510
  452 A= .5*(PG+ AG +2.0*ROP)                                           DK021520
      C= A -PG -ROP                                                     DK021530
      B=SQRT(A*A -C*C)                                                  DK021540
  460 CONTINUE                                                          DK021550
      FTM=.1714E-8*TM**4                                                DK021560
      GO TO 52                                                          DK021570
 4    J=100*K+L                                                         DK021580
      TRASH(14)=WH(4)                                                   DK021590
C          A BLANK FIELD CAUSES PROGRAM TO USE PREVIOUS VALUE OF DATA   DK021600
      READ(30,591) K,(Z(I),I=1,12),AREA,Z(13)                           DK021610
  591 FORMAT(I2,A4,A2,2A1,4(A6,A2),A6,2X,A6)                            DK021620
      READ(30,5914) XNODE                                               DK021630
 5914 FORMAT (50X,F8.0)                                                 DK021640
      IF(NAREA-NBLANK)5911,5913,5911                                    DK021650
C *** IF AREAS ARE INPUT, THERE MUST BE ONE FOR EACH ELEMENT            DK021660
 5911 ZAREA(J)=W(5)                                                     DK021670
      KETCH=1                                                           DK021680
 5913 CONTINUE                                                          DK021690
      IF(NZ(5)-NBLANK) 401,402,401                                      DK021700
 401  ELAMB(J)=W(1)*PI180                                               DK021710
      NTRIG=1                                                           DK021720
      NEWGAM=1                                                          DK021730
```

```
402   IF(NZ(7)-NBLANK) 403,404,403                                              DK021740
403   OMEGA(J)=W(2)*PI180                                                       DK021750
4032  NTRIG=1                                                                   DK021760
      NEWGAM=1                                                                  DK021770
404   IF(NZ(9)-NBLANK) 405,406,405                                              DK021780
405   IZ(J)=W(3)                                                                DK021790
406   IF(NZ(11)-NBLANK) 407,408,407                                             DK021800
407   THICK(J)=W(4)                                                             DK021810
408   IF(NZ(2)-NBLANK) 409,410,409                                              DK021820
409   NCOAT(J)=M                                                                DK021830
410   IF(NZ(3)-NBLANK) 411,412,411                                              DK021840
411   NSUBS(J)=N/10                                                             DK021850
412   IF(NZ(4)-NBLANK) 413,414,413                                              DK021860
413   NDUTY(J)=MOD(N,10)                                                        DK021870
414   NEWMAT=1                                                                  DK021880
4140  WRITE (4,591)K,(Z(I),I=1,12),AREA,Z(13)                                   DK021890
      IF(NZ(13)-NBLANK) 4141,42,4141                                            DK021900
4141  NODE(J)=XNODE                                                             DK021910
42    IF(NODE(J)) 4142,4142,52                                                  DK021920
4142  NODE(J)=J                                                                 DK021930
      GO TO 52                                                                  DK021940
5     KABG=K-3                                                                  DK021950
      LSHADE=L                                                                  DK021960
      PHIN2=W(6)                                                                DK021970
      PHOT2=W(7)                                                                DK021980
C        IF K IS 3, SUN POSITION IS GIVEN BY ALPHA,BETA,GAMMA                   DK021990
C          IF NOT, IT IS GIVEN BY DATA FROM EPHEMERIS AND ORBIT DATA            DK022000
      IF(KABG) 501,508,501                                                      DK022010
501   ANINCL=W(1)                                                               DK022020
C            ASNLNG IS LARGE OMEGA                                              DK022030
C             ASCNOD IS SMALL OMEGA                                             DK022040
      ASCNOD=W(2)                                                               DK022050
      ASNLNG=W(3)                                                               DK022060
      RGTASC=W(4)                                                               DK022070
      DECLIN=W(5)                                                               DK022080
      GO TO 52                                                                  DK022090
508   ALP2=W(1)                                                                 DK022100
      BET2=W(2)                                                                 DK022110
      GAM2=W(3)                                                                 DK022120
      ALPHA2=ALP2*PI180                                                         DK022130
      GAMMA2=GAM2*PI180                                                         DK022140
      BETA2=BET2 *PI180                                                         DK022150
      COSA=COS(ALPHA2)                                                          DK022160
      COSB=COS(BETA2)                                                           DK022170
      COSG=COS(GAMMA2)                                                          DK022180
      SINB=SIN(BETA2)                                                           DK022190
      GO TO 52                                                                  DK022200
6     TQINT(40,K)=10000000.0                                                    DK022210
      CALL QIIN(K,L,W(1))                                                       DK022220
      NEWDC=1                                                                   DK022230
      GO TO 52                                                                  DK022240
7     NSATP=100*K+L                                                             DK022250
      NSATP=MOD(NSATP,201)                                                      DK022260
      GO TO 52                                                                  DK022270
C                  WRITE CASE IDENTIFICATION                                    DK022280
C                WRITE TERMINATION MARK ON SCRATCH TAPES AND REWIND             DK022290
   99 K=0                                                                       DK022300
      WRITE (9,6044)K,(WH(J),J=1,13)                                            DK022310
 6044 FORMAT(I2,13A6)                                                           DK022320
      REWIND 9                                                                  DK022330
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      WRITE (11)K,K,(TQINT(J,1),J=1,41)                                 DK022340
      REWIND 11                                                         DK022350
      WRITE (4,591)K,(Z(J),J=1,12),AREA,Z(13)                           DK022360
      REWIND 4                                                          DK022370
C     WRITE CASE HEADING                                                DK022380
      WRITE (6,640)NUMRUN                                               DK022390
 640  FORMAT(9H1CASE NO.I6)                                             DK022400
C                 TRANSCRIBE COMMENTS                                   DK022410
      DO 101 L=1,15                                                     DK022420
      READ  (9,6044)K,(Z(J),J=1,13)                                     DK022430
      IF(K) 103,103,101                                                 DK022440
 101  WRITE (6,6043)(Z(J),J=1,13)                                       DK022450
6043 FORMAT(1X13A6)                                                     DK022460
 103  K=3*(NORIEN+2)                                                    DK022470
 102  REWIND 9                                                          DK022480
      L=3*KTEMP+3                                                       DK022490
      J=KPLNET+KPLNET                                                   DK022500
      J1=1                                                              DK022510
      WRITE (6,642)ZH(1),WH(J-1),WH(J),WH(4),ZH(2),ZH(3),   XH(K-2),XH(K-DK022520
     11),XH(K),WH(4),ZH(4),ZH(5),ZH(6),YH(L-2),YH(L-1),YH(L)            DK022530
 642  FORMAT(16A6)                                                      DK022540
      EL=ELL(KPLNET)                                                    DK022550
      S=443.0*(BARL/EL)**2                                              DK022560
      CAY=CAYY(KPLNET)                                                  DK022570
      RP=RPP(KPLNET)                                                    DK022580
      R=RR(KPLNET)                                                      DK022590
      RN=SQRT(A*A*A/CAY)/60.0                                           DK022600
      PEE=TWOPI*RN                                                      DK022610
      PEE1=PEE                                                          DK022620
C       IT IS NECESSARY TO RECOMPUTE SIN,COS OF LAMBDA AND OMEGA        DK022630
 701  NEWGAM=0                                                          DK022640
      NTRIG=0                                                           DK022650
      DO 710 J=1,NSATP                                                  DK022660
      SINO(J)=SIN(OMEGA(J))                                             DK022670
      COSO(J)=COS(OMEGA(J))                                             DK022680
      SINL(J)=SIN(ELAMB(J))                                             DK022690
      COSL(J)=COS(ELAMB(J))                                             DK022700
 710  GAMM(J)=ARCOS(SINO(J)*COSL(J))                                    DK022710
 715  IF(NORIEN) 718,720,720                                            DK022720
 718  NTRIG=1                                                           DK022730
C              FIND SIGMA                                               DK022740
 720  NOFIND=LSHADE                                                     DK022750
      CALL SIGBET(KABG,LSHADE)                                          DK022760
      SIGMA2=SIGMA/PI180                                                DK022770
C              PRINT SUN-SHADE POINTS                                   DK022780
      IF(PHIN2+900.0) 6431,6431,6432                                    DK022790
 6431 PIN=0.0                                                           DK022800
      POUT=0.0                                                          DK022810
      SUN=2.0                                                           DK022820
      GO TO 6433                                                        DK022830
 6432 PIN=AMOD(PHIN2+360.0,360.0)                                       DK022840
      POUT=AMOD(PHOUT2+360.0,360.0)                                     DK022850
 6433 WRITE (6,644)AGNM,PGNM,PHIZ2,DPHI2,SIGMA2,BET2,PIN,POUT           DK022860
  644 FORMAT (3X,28HMAX. * ORBIT ALT.(NM) * MIN.,4X,4HPHIO,8X,4HDPHI,8X,DK022870
     15HSIGMA,7X,4HBETA,8X,4HPHIN,8X,5HPHOUT/1XF10.2,9XF11.2,6F12.5)    DK022880
      IF(KABG) 650,645,650                                              DK022890
 645  WRITE (6,646)ALP2,GAM2                                            DK022900
 646  FORMAT(7H ALPHA=F10.5,8H   GAMMA=F10.5)                           DK022910
      GO TO 990                                                         DK022920
 650  WRITE (6,651)ANINCL,ASCNOD,ASNLNG,RGIASC,DECLIN                   DK022930
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651  FORMAT(13H INCLINATION=F10.5,24H  ARGUMENT OF PERIFOCUS=F10.5,21H DK022940
    1 LONG. OF ASC. NODE=F10.5/18H  RIGHT ASCENSION=F10.5,14H  DECLINATDK022950
    2ION=F10.5)                                                          DK022960
990  IF(NEWDC) 150,150,110                                               DK022970
C            TRANSCRIBE NEW INTERNAL HEAT LOADS                          DK022980
110  WRITE (6,109)                                                       DK022990
109  FORMAT(24H0NEW DUTY CYCLES READ IN)                                 DK023000
     DO 140 L=1,8                                                        DK023010
     READ  (11)K,KL,(Z(J),J=1,41)                                        DK023020
     IF(K) 150,150,111                                                   DK023030
111  N=KL+KL+1                                                           DK023040
     IF(Z(41)) 113,113,140                                               DK023050
113  N=2                                                                 DK023060
140  WRITE (6,139)K,(Z(J),J=1,N)                                         DK023070
139  FORMAT(6H0INDEXI2/(6H  QIN=F8.4,4H  T=F8.2,6H  QIN=F8.4,4H  T=F8.2DK023080
    1,6H  QIN=F8.4,4H  T=F8.2,6H  QIN=F8.4,4H  T=F8.2))                  DK023090
150  IF(NEWMAT) 999,999,151                                              DK023100
C             TRANSCRIBE NEW ELEMENTS                                    DK023110
151  WRITE (6,149)                                                       DK023120
149  FORMAT(37H0ELEMENT COATING SUBSTRATE DUTY CYCLE5X5HLAMDA7X5HOMEGA7DK023130
    1X4HT(0)6X9HTHICKNESS4X4HAREA4X8HNODE NO.  )                         DK023140
     DO 170 L=1,200                                                      DK023150
     LL=L                                                                DK023160
     READ  (4,591)K,(Z(J),J=1,12),AREA,Z(13)                             DK023170
     IF(K) 999,999,170                                                   DK023180
 170 WRITE (6,156)(Z(J),J=1,12),AREA,Z(13)                               DK023190
 156 FORMAT(2XA4,6XA2,8XA1,9XA1,9XA6,A2, 4XA6,A2, 4XA6,A2, 4XA6,A2,      DK023200
    12X,A6,4X,A6)                                                        DK023210
C        SET INITIAL TEMPERATURES                                        DK023220
999  DO 998 J=1,NSATP                                                    DK023230
998  T(1,J)=TZ(J)                                                        DK023240
1000 REWIND 11                                                           DK023250
     REWIND4                                                             DK023260
     WRITE (6,461)REV                                                    DK023270
 461 FORMAT (// 35H MAXIMUM NO. OF ORBITS REQUESTED=  F7.3 )             DK023280
     RETURN                                                              DK023290
     END                                                                 DK023300


      FOR      DECK3,DECK3                                               DK030000
     SUBROUTINE LOOP                                                     DK030010
     DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),     DK030020
    1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                     DK030030
     DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),         DK030040
    1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),    DK030050
    2GAMM(200),NDUTY(200)                                                DK030060
     DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)           DK030070
     DIMENSION BUFFER(2)                                                 DK030080
     COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,      DK030090
    1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                              DK030100
     COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV        DK030110
     COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,      DK030120
    1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                      DK030130
     COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                   DK030140
     COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN          DK030150
     COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DFE,DPSQ,J1,J2      DK030160
     COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH                               DK030170
     COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                               DK030180
     COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK         DK030190
     COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                           DK030200
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      COMMON PHI1,PHI2,ISIG,FUDGE,T4,JUDGE,PUFFER,RV,NLINE             DK030210
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,   DK030220
     1COSRS,PHIT,GAMM                                                  DK030230
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,   DK030240
     1DECLIN                                                           DK030250
      DIMENSION AA(6),AA1(6),P(6),P1(6)                                DK030260
      COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,  DK030270
     1YNHAT,ENHATL,EMAG,DERROR,DTTEST                                  DK030280
      COMMON HSUN,HALB,HPLAN,NODE                                      DK030290
      DIMENSION HSUN(200),HALB(200),HPLAN(200),NODE(200)               DK030300
      COMMON KETCH                                                     DK030310
      COMMON HASUN,HAALB,HAPLN,HATOT                                   DK030320
      DIMENSION HASUN(200),HAALB(200),HAPLN(200),HATOT(200)            DK030330
      COMMON ZAREA                                                     DK030340
      DIMENSION ZAREA(200)                                             DK030350
      COMMON IMTHRU                                                    DK030360
      DIMENSION IMTHRU(200)                                            DK030370
      COMMON IMHI,PNAME,PHIPLT,TIMPLT,NPLOT,LAST,JUMP,LMAX,IONCE       DK030380
      DIMENSION PNAME(39),PHIPLT(190),TIMPLT(190)                      DK030390
      COMMON TYME1,TYME2,TYME                                          DK030400
      DIMENSION TPREV(200)                                             DK030410
      DIMENSION ISIBL(200)                                             DK030420
      COMMON/BKIK/JIJK                                                 DK030430
      DO 300 I=1,200                                                   DK030440
  300 IMTHRU(I)=0                                                      DK030450
      IMHI=NSATP                                                       DK030460
      CALL RESET                                                       DK030470
      DO 407 IZ=1,190                                                  DK030480
      PHIPLT(IZ)=0.0                                                   DK030490
  407 TIMPLT(IZ)=0.0                                                   DK030500
C          RESET LINE COUNT AND PRINT PAGE HEADING                     DK030510
      IF(JUDGE-359) 710,711,710                                        DK030520
  710 IF(NQORT-2)600,600,601                                           DK030530
  601 ND=NQORT-2                                                       DK030540
      GO TO 712                                                        DK030550
  600 ND=-NQORT                                                        DK030560
      GO TO 712                                                        DK030570
  711 IF(NQORT-2)603,603,604                                           DK030580
C     WE CALL TOUT BECAUSE IT IS NOT POSSIBLE TO HAVE A BLOCK OUTPUT   DK030590
C     WHEN NQORT IS GREATER THAN 2. TOUT WILL CATCH THIS ERROR,        DK030600
C     PRINT A MESSAGE, AND CALL EXIT...                                DK030610
  604 CALL TOUT(L)                                                     DK030620
      CALL EXIT                                                        DK030630
  603 ND=-3                                                            DK030640
  712 CALL TALLY(NLINE,-1,ND)                                          DK030650
      IF(NQORT*NQORT -3*NQORT)730,732,730                              DK030660
C               COMPUTE MAXIMUMUM TIME INTERVAL                        DK030670
  730 PHI1=(180.0-DPHI2*0.5)*PI180*0.5                                 DK030680
      ZZ1=SIN(PHI1)/COS(PHI1)                                          DK030690
      ZZ1=ATAN((A-C)*ZZ1/B)*2.0                                        DK030700
      IF(ZZ1)861,861,871                                               DK030710
  861 ZZ1=ZZ1+2.0*PI                                                   DK030720
  871 SINZZ1=SIN(ZZ1)                                                  DK030730
      ZZ1=RN*(ZZ1-C*SINZZ1/A)                                          DK030740
      PHI1=PHI1+DPHI2*PI180*0.5                                        DK030750
      ZZ2=SIN(PHI1)/COS(PHI1)                                          DK030760
      ZZ2=ATAN((A-C)*ZZ2/B)*2.0                                        DK030770
      IF(ZZ2) 961,961,971                                              DK030780
  961 ZZ2=ZZ2+2.0*PI                                                   DK030790
  971 SINZZ1=SIN(ZZ2)                                                  DK030800
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      DTMAX=RN*(ZZ2-C*SINZZ1/A)-ZZ1                                      DK030810
C           SET INITIAL TEMPERATURES FOR STEADY STATE TESTS              DK030820
  972 DO 731 J=1,NSATP                                                   DK030830
      IF(IMTHRU(J)) 731,733,731                                          DK030840
  733 TPREV(J)= T(1,J)                                                   DK030850
  731 CONTINUE                                                           DK030860
  732 LINC=360.0/DPHI2+0.5                                               DK030870
      KREV=REV+.9999                                                     DK030880
      ISUN=1                                                             DK030890
C     TAPES  9 (A5) AND 11 (A6) ARE USED AS TEMPORARY STORAGE FOR TEMP.  DK030900
C     AND OTHER VALUABLE INFORMATION...                                  DK030910
  500 IT=9                                                               DK030920
      JT=11                                                              DK030930
      REWIND IT                                                          DK030940
      REWIND JT                                                          DK030950
      KEEP=0                                                             DK030960
      NPTS=0                                                             DK030970
      NDU=0                                                              DK030980
      NSS=0                                                              DK030990
      PHIBAD=-999.0                                                      DK031000
C *** ESTABLISH PHI-IN(FEIN) AND PHI-OUT(FEOUT) VALUES TO BE USED IN     DK031010
C ***   TESTS FOR BAD PHI                                                DK031020
      FEIN=AMOD(PHIN2+360.0,360.0)                                       DK031030
      FEOUT=AMOD(PHOT2+360.0,360.0)                                      DK031040
  501 DO 850 K=1,KREV                                                    DK031050
      NSIBL=1                                                            DK031060
      NORBIT=K                                                           DK031070
      DO 444 IJK=1,NSATP                                                 DK031080
  444 ISIBL(IJK)=0                                                       DK031090
      RV=K                                                               DK031100
      DRRV=REV-RV                                                        DK031110
      IF(NPLOT) 441,442,441                                              DK031120
  441 IF(NQORT-3)442,431,431                                             DK031130
  431 IF(DRRV)432,433,433                                                DK031140
  432 IF(K-1)433,433,442                                                 DK031150
C *** INITIALIZE AVG. EPP CALCULATION                                    DK031160
  433 CALL HEAT (201)                                                    DK031170
  442 IF  (DRRV)741,750,750                                              DK031180
C                  FRACTIONAL ORBIT                                      DK031190
  741 LMAX=360.0*(DRRV+1.0)/DPHI2+0.5                                    DK031200
      GO TO 751                                                          DK031210
C                  COMPLETE ORBIT                                        DK031220
  750 LMAX=LINC                                                          DK031230
  751 DO 800 L=1,LMAX                                                    DK031240
      EEL=L                                                              DK031250
      LL=L                                                               DK031260
      ISKIP=0                                                            DK031270
  752 PHIABS=PHIZ2+EEL*DPHI2                                             DK031280
C *** IF PHIABS IS IN A TROUBLE SPOT , SKIP OUTPUT AT THAT POINT         DK031290
      FE=AMOD(PHIABS,360.0)                                              DK031300
      IF(FE-FEIN )418,419,419                                            DK031310
  419 IF(FE-FEIN -.1)421,421,418                                         DK031320
  418 IF(FE-FEOUT)422,422,423                                            DK031330
  422 IF(FE-FEOUT+.1)423,421,421                                         DK031340
  421 ISKIP=1                                                            DK031350
      IF(ISUN-2)423,800,800                                              DK031360
  423 CONTINUE                                                           DK031370
      IF(SUN-2.0) 3,10,10                                                DK031380
C                      FIND POSITION IN ORBIT                            DK031390
    3 GO TO (200,250),ISUN                                               DK031400
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200   TEST =(PHIABS-PHIN2)*(PHIABS-PHOT2)                                    DK031410
      IF(TEST)260,260,265                                                    DK031420
260   IF(SUN)10,10,210                                                       DK031430
C          SUN-SHADE POINT JUST PASSED -- REDEFINE PHIABS                    DK031440
 210 NSS=-1                                                                  DK031450
      IF(NDO)411,411,412                                                     DK031460
C ***     PHIN2 , SUN                                                        DK031470
 411 PHIABS=PHIN2                                                            DK031480
      ISUN=2                                                                 DK031490
      SUN=1.0                                                                DK031500
      GO TO 10                                                               DK031510
C ***     PHIN2 , SHADE                                                      DK031520
 412 PHIABS=PHIN2 + .1                                                       DK031530
      SUN=0.0                                                                DK031540
      GO TO 10                                                               DK031550
 265  TEST=(PHIABS-PHIN2-360.0)*(PHIABS-PHOT2-360.0)                         DK031560
      IF(TEST) 260,260,266                                                   DK031570
 266  IF(SUN) 205,205,10                                                     DK031580
C             SHADE-SUN POINT JUST PASSED -- REDEFINE PHIABS                 DK031590
 205 NSS=1                                                                   DK031600
      IF(NDO)413,413,414                                                     DK031610
C ***     PHOT2 , SHADE                                                      DK031620
 413 PHIABS =PHOT2 -.1                                                       DK031630
      ISUN=2                                                                 DK031640
      SUN=0.0                                                                DK031650
C *** IF FEOUT-.1 , AT FIRST CALCULATION POINT OF FIRST ORBIT, IS LESS      DK031660
      IF(NORBIT*LL-1)427,427,428                                             DK031670
C ***  THAN PHIZ2 (PHI AT TIME ZERO) WE SHALL ALWAYS SKIP THAT POINT         DK031680
 427 IF(FEOUT-.1-PHIZ2)429,429,10                                            DK031690
 429 PHIBAD=PHIABS                                                           DK031700
 428 IF(ABS(PHIABS-PHIBAD)-.000001)430,430,10                                DK031710
C ***     PHOT2 , SUN                                                        DK031720
 414 PHIABS= PHOT2                                                           DK031730
      SUN=1.0                                                                DK031740
      GO TO 10                                                               DK031750
C             SUN-SHADE POINTS ALREADY CHECKED DURING THIS INTERVAL          DK031760
 250 CONTINUE                                                                DK031770
      ISUN=1                                                                 DK031780
C                CONVERT PHI TO FIRST FOUR QUADRANTS                         DK031790
 10   PHI=AMOD(PHIABS,360.0)                                                 DK031800
      IF(ISKIP)425,425,424                                                   DK031810
 424 IF(ABS(FE-PHI)-.000001)426,426,425                                      DK031820
 426 ISKIP=0                                                                 DK031830
      GO TO 800                                                              DK031840
 425 CALL LOCUS                                                              DK031850
 101  IF(TABS-TIME(J1)+0.5*PEE) 102,12,12                                    DK031860
 102  TABS=TABS+PEE                                                          DK031870
      GO TO 101                                                              DK031880
 12   TIME(J2)=TABS                                                          DK031890
      ZEIT=TABS                                                              DK031900
      IF(KEEP)400,401,400                                                    DK031910
 401 IF(K-1)403,403,402                                                      DK031920
 402 KEEP=1                                                                  DK031930
      GO TO 400                                                              DK031940
 403 IF(NPLOT)443,508,443                                                    DK031950
 443 NPTS=NPTS+1                                                             DK031960
      IF(ABS(PHI)-.01)404,404,405                                            DK031970
 404 PHIPLT(NPTS)=360.0                                                      DK031980
      GO TO 406                                                              DK031990
 405 PHIPLT(NPTS)=AMOD(PHI+360.0,360.0)                                      DK032000
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  406 TIMPLT(NPTS)=ZEIT                                                     DK032010
      GO TO 508                                                            DK032020
  400 READ  (IT)(T(J2,J),HSUN(J),HALB(J),HPLAN(J),HASUN(J),HAALB(J),HAPLDK032030
     1N(J),HATOT(J),J=1,NSATP)                                              DK032040
  508 DO 13 J=1,NSATP                                                       DK032050
      IF(NQORT*NQORT -3*NQORT)503,507,503                                   DK032060
  503 IF(IMTHRU(J))13,505,13                                                DK032070
  505 CALL TEMPER(J)                                                        DK032080
      GO TO 13                                                             DK032090
  507 CALL HEAT(J)                                                          DK032100
 13   CONTINUE                                                              DK032110
      IF(DRRV)21,23,23                                                      DK032120
   21 IF(K-1)23,23,22                                                       DK032130
   23 LAST=JT                                                               DK032140
      WRITE (JT)(T(J2,J),HSUN(J),HALB(J),HPLAN(J),HASUN(J),HAALB(J),HAPLDK032150
     1N(J),HATOT(J),J=1,NSATP)                                              DK032160
   22 CONTINUE                                                              DK032170
      ND= MOD(L,NPRINT)                                                     DK032180
 14   IF(ISUN-2) 15,16,16                                                   DK032190
 15   IF(ND) 17,16,17                                                       DK032200
C                 PRINT AFTER EVERY NPRINT INCREMENTS                       DK032210
   16 CALL TOUT(L)                                                          DK032220
 17   JUB=J1                                                                DK032230
      J1=J2                                                                 DK032240
      J2=JUB                                                                DK032250
  430 IF(NSS)416,415,416                                                    DK032260
  416 IF(NDO)417,417,415                                                    DK032270
  417 NDO=1                                                                 DK032280
      IF(NSS)210,210,205                                                    DK032290
  415 NDO=0                                                                 DK032300
      NSS=0                                                                 DK032310
      IF(ISUN-2) 800,752,752                                                DK032320
 800  CONTINUE                                                              DK032330
      IF (NPLOT)439,438,439                                                 DK032340
  439 IF(NQORT-3)438,437,434                                                DK032350
  434 IF(DRRV) 435,436,436                                                  DK032360
  435 IF(K-1)437,437,438                                                    DK032370
  436 IF(K-KREV) 438,437,437                                                DK032380
C *** CALCULATE AVG. EPP IF IT IS TIME TO DO SO                             DK032390
  437 CALL HEAT (202)                                                       DK032400
  438 CONTINUE                                                              DK032410
      IF(DRRV)99,410,410                                                    DK032420
C           IF TEMPERATURE CYCLE HAS STABILIZED, HALT COMPUTATION           DK032430
  410 IF(NQORT*NQORT -3*NQORT)802,99,802                                    DK032440
C       IMTHRU(I) = 0 MEANS THAT THE TEMPERATURE OF ELEMENT I HAS           DK032450
C       NOT STABILIZED                                                      DK032460
  802 DO 805 IX=1,NSATP                                                     DK032470
      IF(IMTHRU(IX))805,810,805                                             DK032480
  810 IF(ABS(TPREV(IX)-T(J1,IX))- 0.5) 803,803,805                          DK032490
  803 IMTHRU(IX)= K                                                         DK032500
      ISTBL(NSTBL)=IX                                                       DK032510
      NSTBL=NSTBL+1                                                         DK032520
  805 CONTINUE                                                              DK032530
      NSTBL=NSTBL-1                                                         DK032540
      WRITE (6,854)ZEIT,NORBIT                                              DK032550
  854 FORMAT(/ 20H THE OUTPUT AT TIME=  F8.2,19H ENDS ORBIT NUMBER  I3) DK032560
      NLINE=NLINE+5                                                         DK032570
      WRITE (6,408)(ISTBL(IJK),IJK=1,NSTBL)                                 DK032580
  408 FORMAT ( 68H THE TEMPERATURES OF THESE NODES STABILIZED DURING THEDK032590
     1 LAST ORBIT...      12I5 / (1X,26I5) )                                DK032600
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      DO 808 I=1,NSATP                                                      DK032610
      IF(IMTHRU(I))808,809,808                                              DK032620
  808 CONTINUE                                                              DK032630
C *** CALCULATE AVG. EPP IF ALL NODES HAVE STABILIZED                        DK032640
      IF(NPLOT)440,99,440                                                   DK032650
  440 CALL HEAT(202)                                                        DK032660
      GO TO 99                                                              DK032670
  809 CONTINUE                                                              DK032680
      DO 806 IX=1,NSATP                                                     DK032690
      IF(IMTHRU(IX))806,807,806                                             DK032700
  807 TPREV(IX)=T(J1,IX)                                                    DK032710
      IMHI=IX                                                               DK032720
  806 CONTINUE                                                              DK032730
C              RESET STARTING INDEX IN INTERNAL HEAT TABLES                 DK032740
      DO 830 J=1,8                                                          DK032750
      IF(TQINT(41,J)-2.0) 830,830,828                                       DK032760
 828  TQINT(41,J)=2.0                                                       DK032770
 830  CONTINUE                                                              DK032780
      KT=IT                                                                 DK032790
      IT=JT                                                                 DK032800
      JT=KT                                                                 DK032810
      REWIND IT                                                             DK032820
      REWIND JT                                                             DK032830
 850  CONTINUE                                                              DK032840
   99 CONTINUE                                                              DK032850
      CALL CLOCK(TYME1)                                                     DK032860
      IF(NPLOT )10003,10002,10003                                           DK032870
10002 TYME2=0.0                                                             DK032880
      WRITE (6,9999)TYME1                                                   DK032890
 9999 FORMAT(//// 33H CALCULATION TIME FOR THIS CASE =  F6.2,               DK032900
     1 11H MINUTES...     )                                                 DK032910
      RETURN                                                                DK032920
10003 CONTINUE                                                              DK032930
C *** SNEAK AVG. EPP INTO LINK 2                                            DK032940
      CALL HEAT(203)                                                        DK032950
      LMAX=NPTS                                                             DK032960
      WRITE(6,409)                                                          DK032970
  409 FORMAT( /// 68H S-C 4020 PLOTS HAVE BEEN REQUESTED AND SHALL BE PRODK032980
     1OVIDED BY LINK 2    )                                                 DK032990
      CALL MAIN2                                                            DK033000
      JIJK=1                                                                DK033010
      RETURN                                                                DK033020
      END                                                                   DK033030

       FOR      DECK4,DECK4                                                 DK040000
      SUBROUTINE TOUT(L)                                                    DK040010
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),       DK040020
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                       DK040030
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),           DK040040
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),      DK040050
     2GAMM(200),NDUTY(200)                                                  DK040060
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)             DK040070
      DIMENSION BUFFER(2)                                                   DK040080
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,        DK040090
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                                DK040100
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV          DK040110
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,        DK040120
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                        DK040130
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                     DK040140
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      COMMON PHIZ2,DPHI2,PHIZ,DPHI,XHI,CPHI,SPHI,PHIN2,PHOT2,SUN        DK040150
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2    DK040160
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH                             DK040170
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                             DK040180
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK       DK040190
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                         DK040200
      COMMON PHI1,PHI2,ISIG,FUDGE,TPL,JUDGE,BUFFER,RV,NLINE             DK040210
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,    DK040220
     1COSRS,PHIT,GAMM                                                   DK040230
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,    DK040240
     1DECLIN                                                            DK040250
      DIMENSION AA(6),AA1(6),P(6),P1(6)                                 DK040260
      COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,   DK040270
     1YNHAT,ENHATL,EMAG,DERROR,DTTEST                                   DK040280
      COMMON HSUN,HALB,HPLAN,NODE                                       DK040290
      DIMENSION HSUN(200),HALB(200),HPLAN(200),NODE(200)                DK040300
      COMMON KETCH                                                      DK040310
      COMMON HASUN,HAALB,HAPLN,HATOT                                    DK040320
      DIMENSION HASUN(200),HAALB(200),HAPLN(200),HATOT(200)             DK040330
      COMMON ZAREA                                                      DK040340
      DIMENSION ZAREA(200)                                              DK040350
      PHI=XHI                                                           DK040360
      IF(PHI) 38,39,39                                                  DK040370
38    PHI=PHI+360.0                                                     DK040380
   39 IF(JUDGE-359)40,100,40                                            DK040390
  100 IF(NQORT-2)10,10,1000                                             DK040400
 1000 WRITE (6,1001)NQORT                                               DK040410
 1001 FORMAT (1H1,//////////35H YOU WANT A BLOCK OUTPUT FOR NQORT=I3 // DK040420
    1 61H THIS IS NOT POSSIBLE AT THE PRESENT TIME...I SHALL CALL EXIT)DK040430
      CALL EXIT                                                         DK040440
40    K1=1                                                              DK040450
      IF(NQORT-2)512,512,513                                            DK040460
  513 NARG=NQORT-2                                                      DK040470
      GO TO 514                                                         DK040480
  512 NARG = -NQORT                                                     DK040490
  514 CALL TALLY(NLINE ,2,NARG)                                         DK040500
      IF(NQORT-1)41,61,510                                              DK040510
  510 IF(NQORT-2)51,51,511                                              DK040520
  511 IF(NQORT-3)81,81,91                                               DK040530
C                HEAT ONLY                                              DK040540
41    WRITE (6,411)PHI,ZEIT,NODE(1),HSUN(1),HALB(1),HPLAN(1)            DK040550
      IF(NSATP-2)99,42,42                                               DK040560
42    DO 43 J=2,NSATP                                                   DK040570
      CALL TALLY(NLINE,1,-NQORT)                                        DK040580
43    WRITE (6,412)NODE(J),HSUN(J),HALB(J),HPLAN(J)                     DK040590
411   FORMAT(/F6.1,F8.2,1XI3,4F10.2)                                    DK040600
412   FORMAT(15XI3,4F10.2)                                              DK040610
      GO TO 99                                                          DK040620
51    WRITE (6,411)PHI,ZEIT,NODE(1),T(J2,1),HSUN(1),HALB(1),HPLAN(1)    DK040630
      IF(NSATP-2)99,52,52                                               DK040640
52    DO 53 J=2,NSATP                                                   DK040650
      CALL TALLY(NLINE,1,-NQORT)                                        DK040660
53    WRITE (6,412)NODE(J),T(J2,J),HSUN(J),HALB(J),HPLAN(J)             DK040670
      GO TO 99                                                          DK040680
61    WRITE (6,411)PHI,ZEIT,NODE(1),T(J2,1)                             DK040690
      IF(NSATP-2)99,62,62                                               DK040700
62    DO 63 J=2,NSATP                                                   DK040710
      CALL TALLY(NLINE,1,-NQORT)                                        DK040720
63    WRITE (6,412)NODE(J),T(J2,J)                                      DK040730
      GO TO 99                                                          DK040740
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C                INCIDENT AND ABSORBED HEATS                                 DK040750
   81 WRITE (6,810)PHI,ZEIT,NODE(1),HSUN(1),HALB(1),HPLAN(1), HASUN(1),HDK040760
     1AALB(1),HAPLN(1),HATOT(1)                                              DK040770
  810 FORMAT( /F6.1,F8.2,1XI3,3F10.2,11X,4F10.2)                             DK040780
      IF(NSATP-2)99,82,82                                                    DK040790
   82 DO 83 J=2,NSATP                                                        DK040800
      CALL TALLY(NLINE,1,1)                                                  DK040810
   83 WRITE (6,830)NODE(J),HSUN(J),HALB(J),HPLAN(J),HASUN(J),HAALB(J),HADK040820
     1PLN(J),HATOT(J)                                                        DK040830
  830 FORMAT (15XI3, 3F10.2,11X,4F10.2)                                      DK040840
      GO TO 99                                                               DK040850
C              TEMPERATURE,INCIDENT HEAT, AND ABSORBED HEAT                  DK040860
   91 WRITE (6,910)PHI,ZEIT,NODE(1),T(J2,1),HSUN(1),HALB(1), HPLAN(1),HADK040870
     1SUN(1),HAALB(1),HAPLN(1),HATOT(1)                                      DK040880
  910 FORMAT (/F6.1,F8.2,1XI3,4F10.2,11X,4F10.2)                             DK040890
      IF(NSATP-2)99,92,92                                                    DK040900
   92 DO 93 J=2,NSATP                                                        DK040910
      CALL TALLY (NLINE,1,2)                                                 DK040920
   93 WRITE (6,930)NODE(J),T(J2,J),HSUN(J),HALB(J),HPLAN(J), HASUN(J),HADK040930
     1ALB(J),HAPLN(J),HATOT(J)                                               DK040940
  930 FORMAT (15XI3,4F10.2,11X,4F10.2)                                       DK040950
      GO TO 99                                                               DK040960
 10   L8=(NSATP+9)/10                                                        DK040970
      CALL TALLY(NLINE,L8+2,-3)                                              DK040980
      IF(NQORT-1) 11,21,21                                                   DK040990
C                   ONLY HEAT FLUXES ARE REQUIRED                            DK041000
 11   WRITE (6,702)PHI,ZEIT                                                  DK041010
 12   CALL ARROUT(HSUN(1),L8,NSATP)                                          DK041020
      GO TO 31                                                               DK041030
C                     TEMPERATURES REQUIRED                                  DK041040
 21   WRITE (6,701)PHI,ZEIT                                                  DK041050
      DO 23 J=1,NSATP,10                                                     DK041060
      NF=MIN0(10*J,NSATP)                                                    DK041070
 23   WRITE (6,705)J,(T(J2,N),N=J,NF)                                        DK041080
 705  FORMAT(14XI4,2X10F10.2)                                                DK041090
      IF(NQORT-1) 99,99,25                                                   DK041100
C           HEAT FLUXES AS WELL AS TEMPERATURES NEEDED                       DK041110
 25   CALL TALLY(NLINE,L8+2,-3)                                              DK041120
      WRITE (6,706)                                                          DK041130
      GO TO 12                                                               DK041140
 31   CALL TALLY(NLINE,L8+2,-3)                                              DK041150
 32   WRITE (6,703)                                                          DK041160
      CALL ARROUT(HALB(1),L8,NSATP)                                          DK041170
      CALL TALLY(NLINE,L8+2,-3)                                              DK041180
 34   WRITE (6,704)                                                          DK041190
      CALL ARROUT(HPLAN(1),L8,NSATP)                                         DK041200
 701  FORMAT(/F6.1,F9.2,14H   TEMPERATURES)                                  DK041210
 702  FORMAT(/F6.1,F9.2,10H   Q SOLAR )                                      DK041220
 703  FORMAT(/17X8HQ ALBEDO)                                                 DK041230
 704  FORMAT(/17X8HQ PLANET)                                                 DK041240
 706  FORMAT(/17X8HQ SOLAR )                                                 DK041250
   99 RETURN                                                                 DK041260
      END                                                                    DK041270


       FOR     DECK5,DECK5                                                   DK050000
      SUBROUTINE HEAT(J)                                                     DK050010
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),        DK050020
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                        DK050030
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),            DK050040
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     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),
     2GAMM(200),NDUTY(200)
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DFE,DPSQ,J1,J2
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF
      COMMON PHI1,PHI2,ISIG,FUDGE,T4,JUDGE,TPL,BUFFER,RV,NLINE
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,
     1COSRS,PHIT,GAMM
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,
     1DECLIN
      DIMENSION AA(6),AA1(6),P(6),P1(6)
      COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,
     1YNHAT,ENHATL,EMAG,DERROR,DTTEST
      COMMON HSUN,HALB,HPLAN,NODE
      DIMENSION HSUN(200),HALB(200),HPLAN(200),NODE(200)
      COMMON KETCH
      COMMON HASUN,HAALB,HAPLN,HATOT
      DIMENSION HASUN(200),HAALB(200),HAPLN(200),HATOT(200)
      COMMON ZAREA
      DIMENSION ZAREA(200)
      COMMON IMTHRU
      DIMENSION IMTHRU(200)
      DIMENSION DARK(200), BRITE(200),NBRITF(200)
      IF(J-201)100,101,102
C *** INITIALIZE CALCULATION OF AVG. EPP (PLANET ABSORPTIVITY) TO BE
C     OUTPUT ON SC-4020 PLOTS
  101 DO 103 I=1,NSATP
      IF (IMTHRU(I))103,108,103
  108 DARK(I)=0.0
      BRITE(I)=0.0
      NBRITF(I)=0
  103 CONTINUE
      GO TO 999
  102 IF(J-202)109,109,110
C *** CALCULATE AVG. EPP FOR SUN SIDE
 109  DO 104 I=1,NSATP
  104 BRITE(I)=BRITE(I)/FLOAT(NBRITE(I))
      GO TO 999
C *** SAVE DARK(I) AND BRITE(I) IN TWO ARRAYS WHICH ARE IN COMMON BUT
C     NO LONGER USED IN THIS CASE
  110 DO 111 I=1,NSATP
      HSUN(I) =DARK(I)
  111 HALB(I)=BRITE(I)
      GO TO 999
  100 CONTINUE
      JSAT=J
C           DETERMINE VALUES NEEDED FOR J TH ELEMENT
      GAM=GAMM(JSAT)
      PHIC=PHIT(JSAT)
      JC=NCOAT(JSAT)
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      JS=NSUBS(JSAT)                                                    DK050650
      AS=ESUN(JC)                                                       DK050660
      TEMT=T(J1,JSAT)                                                   DK050670
      CALL INTERP(EEE(1,1),TEMT,JC,EPSLN)                               DK050680
      CALL INTERP(RO(1,1),TEMT,JS,RHO)                                  DK050690
      CALL INTERP(SP(1,1),TEMT,JS,CP)                                   DK050700
      CALL INTERP(EEE(1,1),TPL,JC,EPP)                                  DK050710
      EPSIG2=-3.428E-09*EPSLN                                           DK050720
      RHRCP=1.0/(RHO*CP*THICK(JSAT)*60.0)                               DK050730
      KODE=(3.0-SUN)*3.0*SUN                                            DK050740
      KODE=KODE+3+KTEMP+NORIEN+NORIEN                                   DK050750
 5    GO TO (35,36,33,34,35,36,41,42,33,40,41,42),KODE                  DK050760
C          SPINNING,CONSTANT PLANET TEMPERATURE                         DK050770
 33   FPLAN=0.25*FD                                                     DK050780
      IF(SUN) 331,50,331                                                DK050790
 331  FSUN=0.5                                                          DK050800
      FALB=0.0                                                          DK050810
      IF(CTHET) 60,60,332                                               DK050820
 332  FALB=FD*CTHET                                                     DK050830
      GO TO 60                                                          DK050840
C          SPINNING,SHADE,VARIABLE PLANET TEMPERATURE                   DK050850
 34   FPLAN=FTM*FD/(S*(1.0-R))                                          DK050860
      GO TO 50                                                          DK050870
C          ORIENTED,SHADE,CONSTANT PLANET TEMPERATURE                   DK050880
 35   ANGS=0.0                                                          DK050890
      CALL GEOFAC(FF)                                                   DK050900
      FPLAN=0.5*FF                                                      DK050910
      GO TO 50                                                          DK050920
C          ORIENTED,SHADE,VARIABLE PLANET TEMPERATURE                   DK050930
 36   ANGS=0.0                                                          DK050940
      CALL GEOFAC(FF)                                                   DK050950
      FPLAN=2.0*FTM*FF/(S*(1.0-R))                                      DK050960
      GO TO 50                                                          DK050970
C          SPINNING, SUN ,VARIABLE PLANET TEMPERATURE                   DK050980
 40   FPLAN=FD*CTHET                                                    DK050990
      RUB=FTM*FD/(S*(1.0-R))                                            DK051000
      IF(FPLAN-RUB) 401,331,331                                         DK051010
 401  FPLAN=RUB                                                         DK051020
      GO TO 331                                                         DK051030
C          ORIENTED, SUN ,CONSTANT PLANET TEMPERATURE                   DK051040
 41   STANG=ANGS                                                        DK051050
      ANGS=0.0                                                          DK051060
      CALL GEOFAC(FF)                                                   DK051070
      ANGS=STANG                                                        DK051080
      FPLAN=0.5*FF                                                      DK051090
 411  CALL GEOFAC(FF)                                                   DK051100
      FALB=FF+FF                                                        DK051110
      IF(FALB) 412,415,415                                              DK051120
 412  FALB=0.0                                                          DK051130
 415  FSUN=2.0*COSRS(JSAT)                                              DK051140
      IF(FSUN) 416,60,60                                                DK051150
 416  FSUN=0.0                                                          DK051160
      GOTO 60                                                           DK051170
C          ORIENTED, SUN ,VARIABLE PLANET TEMPERATURE                   DK051180
 42   CALL GEOFAC(FF)                                                   DK051190
      FPLAN=FF+FF                                                       DK051200
      FALB=FPLAN                                                        DK051210
      STANG=ANGS                                                        DK051220
      ANGS=0.0                                                          DK051230
      CALL GEOFAC(FF)                                                   DK051240
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      ANGS=STANG                                                        DK051250
      RUB=2.0*FTM*FF/(S*(1.0-R))                                        DK051260
      IF(FPLAN-RUB) 420,420,422                                         DK051270
420   FPLAN=RUB                                                         DK051280
422   IF(FALB) 412,415,415                                              DK051290
50    FSUN=0.0                                                          DK051300
49    FALB=0.0                                                          DK051310
60    QSUN=FSUN*SAS2                                                    DK051320
      QALB=FALB*SRASH                                                   DK051330
      QPLAN=FPLAN*EPTP4                                                 DK051340
      QSUN=AMAX1(QSUN,0.0)                                              DK051350
      QALB=AMAX1(QALB,0.0)                                              DK051360
      QPLAN=AMAX1(QPLAN,0.0)                                            DK051370
      QEXT=QSUN+QALB+QPLAN                                              DK051380
      QNET=AS*(QSUN+QALB)+EPP*QPLAN                                     DK051390
      AQSUN=AS*QSUN                                                     DK051400
      AQALB=AS*QALB                                                     DK051410
      AQPLN=EPP*QPLAN                                                   DK051420
      ATOT=QNET                                                         DK051430
      IF(ZAREA(JSAT)) 501,501,500                                       DK051440
  500 AQSUN=AQSUN* ZAREA(JSAT)                                          DK051450
      AQALB=AQALB* ZAREA(JSAT)                                          DK051460
      AQPLN=AQPLN* ZAREA(JSAT)                                          DK051470
      ATOT=ATOT*   ZAREA(JSAT)                                          DK051480
  501 F4=1.0                                                            DK051490
      IF(NORIEN) 607,606,607                                            DK051500
 606  F4=4.0                                                            DK051510
 607  HSUN(JSAT)=F4*QSUN                                                DK051520
      HALB(JSAT)=F4*QALB                                                DK051530
      HPLAN(JSAT)=F4*QPLAN                                              DK051540
      HASUN(JSAT)=F4*AQSUN                                              DK051550
      HAALB(JSAT)=F4*AQALB                                              DK051560
      HAPLN(JSAT)=F4*AQPLN                                              DK051570
      HATOT(JSAT)=ATOT*F4                                               DK051580
      IF(NQORT*NQORT -3*NQORT)61,71,61                                  DK051590
 61   CALL QIFIND(JSAT,TELAPS-TIMEZ,TBREAK,QNEW,QOLD)                   DK051600
 71   GO TO 99                                                          DK051610
   99 IF(NQORT -3)999,105,105                                           DK051620
  105 IF (SUN-1.0)106,107,107                                           DK051630
C *** EPP FOR SHADE SIDE (CONSTANT)                                     DK051640
  106 DARK(JSAT) =EPP                                                   DK051650
      GO TO 999                                                         DK051660
C *** ACCUMULATE EPP FOR  SUN  SIDE                                     DK051670
  107 NBRITE(JSAT) =NBRITE(JSAT) +1                                     DK051680
      BRITE (JSAT) =BRITE(JSAT) +EPP                                    DK051690
  999 RETURN                                                            DK051700
      END                                                               DK051710

•       FOR     DECK6,DECK6                                             DK060000
      SUBROUTINE FREAD                                                  DK060010
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),   DK060020
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                   DK060030
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),       DK060040
     1COSO(200),THICK(200),NCOAT(200),NSURS(200),COSRS(200),PHIT(200),  DK060050
     2GAMM(200),NDUTY(200)                                              DK060060
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)         DK060070
      DIMENSION BUFFER(10)                                              DK060080
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,    DK060090
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                            DK060100
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      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF
      COMMON BUFFER
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,
     1COSRS,PHIT,GAMM
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,
     1DECLIN
      DIMENSION Z(13)
      HTAB(1)=-1.E20
      HTAB(2)=100.0
      HTAB(3)=300.0
      HTAB(4)=600.0
      HTAB(5)=1000.0
      HTAB(6)=3000.0
      HTAB(7)=6000.0
      HTAB(8)=10000.0
      HTAB(9)=20000.0
      ANGTAB(1)=0.0
      ANGTAB(2)=20.0
      ANGTAB(3)=30.0
      ANGTAB(4)=40.0
      ANGTAB(5)=50.0
      ANGTAB(6)=60.0
      ANGTAB(7)=70.0
      ANGTAB(8)=80.0
      ANGTAB(9)=85.0
      ANGTAB(10)=90.0
      READ(5,600) ((F(J,K,1),J=1,10),K=2,9)
      READ(5,600) (((F(J,K,L),J=1,10),K=2,9),L=8,42)
  600 FORMAT(20F4.4)
      DO 47 L=2,7
      DO 47 K=2,9
      DO 47 J=1,10
   47 F(J,K,L)=F(J,K,1)
C        CONSTANTS WHICH ARE DEFINED ONLY FIRST TIME AROUND
      PI=3.1415927
      TWOPI=6.2831853
      PIH=1.5707963
      PI180=.017453293
      BARL=48.89E10
      ELL(1)=48.89E10
      ELL(2)=48.89E10
      ELL(3)=255.3E10
      ELL(4)=74.81E10
      ELL(5)=19.03E10
      ELL(6)=1475.E10
      ELL(7)=467.9E10
      ELL(8)=941.3E10
      ELL(9)=35.43E10
      CAYY(1)=141.E14
      CAYY(2)=1.731E14
      CAYY(3)=44900.E14
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      CAYY(4)=15.20E14                                                  DK060710
      CAYY(5)=7.66E14                                                   DK060720
      CAYY(6)=2435.E14                                                  DK060730
      CAYY(7)=13450.E14                                                 DK060740
      CAYY(8)=2058.E14                                                  DK060750
      CAYY(9)=114.8E14                                                  DK060760
      RPP(1)=20.9E6                                                     DK060770
      RPP(2)=5.702E6                                                    DK060780
      RPP(3)=229.3E6                                                    DK060790
      RPP(4)=10.87E6                                                    DK060800
      RPP(5)=8.151E6                                                    DK060810
      RPP(6)=81.51E6                                                    DK060820
      RPP(7)=188.7E6                                                    DK060830
      RPP(8)=83.6E6                                                     DK060840
      RPP(9)=20.34E6                                                    DK060850
C *** EARTH ALBEDO CHANGED APR. 1966 (WAS=.39)                           DK060860
      RR(1)=.35                                                         DK060870
      RR(2)=.047                                                        DK060880
      RR(3)=.51                                                         DK060890
      RR(4)=.148                                                        DK060900
      RR(5)=.058                                                        DK060910
      RR(6)=.62                                                         DK060920
      RR(7)=.50                                                         DK060930
      RR(8)=.66                                                         DK060940
      RR(9)=.76                                                         DK060950
      DO 14 J=1,200                                                     DK060960
      NCOAT(J)=1                                                        DK060970
      NSUBS(J)=1                                                        DK060980
      NDUTY(J)=1                                                        DK060990
      THICK(J)=.01                                                      DK061000
      SINO(J)=0.0                                                       DK061010
      COSO(J)=1.0                                                       DK061020
      SINL(J)=0.0                                                       DK061030
      COSL(J)=1.0                                                       DK061040
   14 GAMM(J)=90.0                                                      DK061050
C        READ IN HEADING INFORMATION                                    DK061060
      READ(5,641) (ZH(J),J=1,6),(YH(J),J=1,6),(XH(J),J=1,9),(WH(J),J=1,1DK061070
     18)                                                                DK061080
  641 FORMAT(13A6)                                                      DK061090
C          READ COMMENT CARDS                                           DK061100
   30 READ(5,405) KK,(Z(J),J=1,13)                                      DK061110
  405 FORMAT(I2,13A6)                                                   DK061120
      IF(9-KK)37,37,38                                                  DK061130
   37 WRITE(6,406) (Z(J),J=1,13)                                        DK061140
  406 FORMAT(/1X13A6)                                                   DK061150
      GO TO 30                                                          DK061160
C        READ IN TABLES OF MATERIAL PROPERTIES                          DK061170
   38 CONTINUE                                                          DK061180
  300 READ(30,400) KCOAT,KSUBS                                          DK061190
  400 FORMAT(2I2)                                                       DK061200
C         THERE ARE KCOAT COATING TABLES, KSUBS SUBSTRATE TABLES        DK061210
      DO 301 M=1,KCOAT                                                  DK061220
      CALL TABLE(EEE(1,1),1,M)                                          DK061230
  301 ESUN(M)=EEE(M,42)                                                 DK061240
      DO 302 M=1,KSUBS                                                  DK061250
      CALL TABLE(SP(1,1),0,M)                                           DK061260
  302 CALL TABLE(RO(1,1),0,M)                                           DK061270
   99 RETURN                                                            DK061280
      END                                                               DK061290
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      FOR      DECK7,DECK7
      SUBROUTINE QIFIND(JSAT,TIMD,TB,QN,QA)
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),
     2GAMM(200),NDUTY(200)
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)
      DIMENSION BUFFER(10)
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF
      COMMON BUFFER
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,
     1COSRS,PHIT,GAMM
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,
     1DECLIN
      DIMENSION AA(6),AA1(6),P(6),P1(6)
      COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,
     1YNHAT,ENHATL,EMAG,DERROR,DTTEST
      COMMON HSUN,HALB,HPLAN,NODE
      DIMENSION HSUN(200),HALB(200),HPLAN(200),NODE(200)
      COMMON KETCH
      COMMON HASUN,HAALB,HAPLN,HATOT
      DIMENSION HASUN(200),HAALB(200),HAPLN(200),HATOT(200)
      COMMON ZAREA
      DIMENSION ZAREA(200)
      COMMON IMTHRU
      DIMENSION IMTHRU(200)
      COMMON IMHI
      N=NDUTY(JSAT)
      TID=AMOD(TIMD,PEE)
      IF(TID) 92,92,95
   92 TID=TID+PEE
C           FIND TIME AT START OF INTERVAL
   95 TA=TID-ABS(TIME(J1)-TIME(J2))
      K=TQINT(41,N)
C           IF TQINT(41)=0, SET QINT=0.
C               IF TQINT(41) IS 2., 4.,... USE THIS AS INDEX FOR TESTS
      IF(K) 96,96,5
   96 QOLD=0.0
   97 QNEW=QOLD
C                NO CHANGE THIS TIME
      TBREAK=TID
   99 TB=TBREAK
      QN=QNEW
      QA=QOLD
  100 IF(IMHI -JSAT)101,101,105
C     ADVANCE INTERNAL HEAT TABLE INDEX AFTER PROCESSING LAST ELEMENT
  101 DO 104 J=1,8
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      N=IQINT(41,J)                                                      DK070590
      IF(N)104,104,102                                                   DK070600
  102 IF(TQINT(N,J)-TID) 103,104,104                                     DK070610
  103 TQINT(41,J)=IQINT(41,J)+2.0                                        DK070620
      N=IQINT(41,J)                                                      DK070630
      GO TO 102                                                          DK070640
  104 CONTINUE                                                           DK070650
  105 RETURN                                                             DK070660
  5   IF(TID-TQINT(K,N)) 6,6,7                                           DK070670
  6   QOLD=TQINT(K-1,N)                                                  DK070680
      GO TO 97                                                           DK070690
  7   TBREAK=TQINT(K,N)                                                  DK070700
C                QINT CHANGES THIS TIME                                  DK070710
      QOLD=TQINT(K-1,N)                                                  DK070720
      QNEW=TQINT(K+1,N)                                                  DK070730
  71  IF(K-38) 98,8,8                                                    DK070740
  98  K=K+2                                                              DK070750
      IF(TID-TQINT(K,N)) 99,99,991                                       DK070760
C            MORE THAN ONE CHANGE THIS INTERVAL                          DK070770
C            FIND AVERAGE QOLD                                           DK070780
  991 QOLD=QNEW*(TQINT(K,N)-TQINT(K-2,N))+QOLD*(TQINT(K-2,N)-TA)         DK070790
      QNEW=TQINT(K+1,N)                                                  DK070800
      GO TO 71                                                           DK070810
  8   TQINT(40,N)=100000000.0                                            DK070820
      GO TO 99                                                           DK070830
      END                                                                DK070840
*      FOR      DECK8,DECK8                                              DK080000
      SUBROUTINE TALLY(N,ND,NQ)                                          DK080010
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),    DK080020
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                   DK080030
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),        DK080040
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),   DK080050
     2GAMM(200),NDUTY(200)                                               DK080060
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)          DK080070
      DIMENSION BUFFER(2)                                                DK080080
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,     DK080090
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                             DK080100
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV       DK080110
      COMMON A,B,C,AYF,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BFT2,GAM2,     DK080120
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                     DK080130
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                  DK080140
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,XHI,CPHI,SPHI,PHIN2,PHOT2,SUN         DK080150
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DFE,DPSQ,J1,J2     DK080160
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH                              DK080170
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                              DK080180
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK        DK080190
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                          DK080200
      COMMON PHI1,PHI2,ISIG,FUDGE,TPL,JUDGE,BUFFER,RV,NLINE              DK080210
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,     DK080220
     1COSRS,PHIT,GAMM                                                    DK080230
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,     DK080240
     1DECLIN                                                             DK080250
      DIMENSION AA(6),AA1(6),P(6),P1(6)                                  DK080260
      COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,FN1,FN,FACT,    DK080270
     1YNHAT,ENHATL,EMAG,DERROR,DTTEST                                    DK080280
      COMMON HSUN,HALB,HPLAN,NODE                                        DK080290
      DIMENSION HSUN(200),HALB(200),HPLAN(200),NODE(200)                 DK080300
      COMMON KETCH                                                       DK080310
      NC=NQ+4                                                            DK080320
      IF(ND) 9,9,8                                                       DK080330
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C        IF ND IS NEGATIVE,START NEW PAGE                                DK080340
 9     N=1                                                               DK080350
   90 GO TO (1,2,3,4,5,6),NC                                             DK080360
 1     WRITE (6,700)                                                     DK080370
       GO TO 20                                                          DK080380
    2 WRITE (6,7011)                                                     DK080390
 7011 FORMAT(1H1,33X,22HINCIDENT(BTU/HR-FT**2)//)                        DK080400
       WRITE (6,701)                                                     DK080410
       GO TO 20                                                          DK080420
 3     WRITE (6,702)                                                     DK080430
       GO TO 20                                                          DK080440
    4 WRITE (6,7033)                                                     DK080450
 7033 FORMAT(1H1,23X,22HINCIDENT(BTU/HR-FT**2)//)                        DK080460
       WRITE (6,703)                                                     DK080470
       GO TO 20                                                          DK080480
C      KETCH COMES FROM SUBROUTINE TINPUT. WHEN KETCH =0 , WE HAVE       DK080490
C      NO AREA INPUT                                                     DK080500
    5 IF(KETCH)51,52,51                                                  DK080510
   51 WRITE (6,53)                                                       DK080520
   53 FORMAT(1H1,24X,22HINCIDENT(BTU/HR-FT**2),27X16HABSORBED(BTU/HR)//)DK080530
      GO TO 55                                                           DK080540
   52 WRITE (6,54)                                                       DK080550
   54 FORMAT(1H1,24X,22HINCIDENT(BTU/HR-FT**2),23X22HABSORBED(BTU/HR-FT*DK080560
     1*2)//)                                                             DK080570
   55 WRITE (6,705)                                                      DK080580
      GO TO 20                                                           DK080590
    6 IF(KETCH)61,62,61                                                  DK080600
   61 WRITE (6,63)                                                       DK080610
   63 FORMAT(1H1,34X,22HINCIDENT(BTU/HR-FT**2),27X16HABSORBED(BTU/HR)//)DK080620
      GO TO 65                                                           DK080630
   62 WRITE (6,64)                                                       DK080640
   64 FORMAT(1H1,34X,22HINCIDENT(BTU/HR-FT**2),23X22HABSORBED(BTU/HR-FT*DK080650
     1*2)//)                                                             DK080660
   65 WRITE (6,706)                                                      DK080670
      GO TO 20                                                           DK080680
 8     N=N+ND                                                            DK080690
       IF(N-56) 20,20,10                                                 DK080700
C         IF ND CAUSES LINE COUNT TO EXCEED 57, START NEW PAGE           DK080710
 10    N=ND                                                              DK080720
       GO TO 90                                                          DK080730
 700   FORMAT(6H1    PHI5X4HTIME2X28HTEMPERATURE AND/OR HEAT FLUX)       DK080740
 701   FORMAT(6H     PHI5X4HTIME2X11HTEMPERATURE4X6HQSOLAR3X7HQALBEDO3X7HQPDK080750
     1LANET)                                                             DK080760
 702   FORMAT(6H1    PHI5X4HTIME2X11HTEMPERATURE)                        DK080770
 703   FORMAT(6H     PHI5X4HTIME7X6HQSOLAR3X7HQALBEDO3X7HQPLANET)        DK080780
  705 FORMAT(                            6H     PHI5X4HTIME7X6HQSOLAR3X, DK080790
     17HQALBEDO3X7HQPLANET15X6HQSOLAR3X7HQALBEDO3X7HQPLANET4X6HQTOTAL ) DK080800
  706 FORMAT(                            6H     PHI5X4HTIME2X11HTEMPERATUDK080810
     1RE4X6HQSOLAR3X7HQALBEDO3X7HQPLANET15X6HQSOLAR3X7HQALBEDO3X7HQPLANEDK080820
     2T4X6HQTOTAL )                                                      DK080830
 20    RETURN                                                            DK080840
       END                                                               DK080850


        FOR      DECK9,DECK9                                             DK090000
       SUBROUTINE LOCUS                                                  DK090010
       DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),   DK090020
      1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                   DK090030
       DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),       DK090040
      1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),  DK090050
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      2GAMM(200)                                                       DK090060
       DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)       DK090070
       COMMON TRASH,F,HIAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,  DK090080
      1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                          DK090090
       COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV    DK090100
       COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,  DK090110
      1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                  DK090120
       COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                               DK090130
       COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN      DK090140
       COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2  DK090150
       COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH                           DK090160
       COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                           DK090170
       COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK     DK090180
       COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                       DK090190
       COMMON PHI1,PHI2,ISIG,FUDGE,T4,JUDGE,TPL,BUFFER,RV,NLINE        DK090200
       COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,  DK090210
      1COSRS,PHIT,GAMM                                                 DK090220
       COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,  DK090230
      1DECLIN                                                          DK090240
       DIMENSION AA(6),AA1(6),P(6),P1(6)                               DK090250
       COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT, DK090260
      1YNHAT,ENHATL,EMAG,DERROR,DTTEST                                 DK090270
       COMMON HSUN,HALB,HPLAN,NODE                                     DK090280
       DIMENSION HSUN(200),HALB(200),HPLAN(200),NODE(200)              DK090290
C                 FIND TIME AS A FUNCTION OF PHI. ALSO FIND X AND Y    DK090300
       PHIH=0.5*PI180*PHI                                              DK090310
       PHIR=PHIH+PHIH                                                  DK090320
       TPHIH=SIN(PHIH)/COS(PHIH)                                       DK090330
       ATP=(A-C)*TPHIH/B                                               DK090340
       EE=ATAN(ATP)*2.0                                                DK090350
       IF(EE) 8,8,9                                                    DK090360
 8     EE=EE+TWOPI                                                     DK090370
 9     SINEE=SIN(EE)                                                   DK090380
       TELAPS=RN*(EE-C*SINEE/A)                                        DK090390
 10    XP=COS(EE)*A        -C                                          DK090400
       YP=SINEE*B                                                      DK090410
C           FIND USEFUL QUANTITIES DEPENDING ONLY ON SATELLITE LOCATIONDK090420
       DPSQ=XP*XP+YP*YP                                                DK090430
       DEE=SQRT(DPSQ)                                                  DK090440
       FD=1.0-SQRT(1.0-RP/DPSQ*RP)                                     DK090450
       CTHET=(XP*COSA+YP*COSG)/DEE                                     DK090460
       TPL=T4                                                          DK090470
       IF(KTEMP)208,208,201                                            DK090480
 201   IF(CTHET)205,205,202                                            DK090490
 202   TPL=T4*SQRT(SQRT(4.0*CTHET))                                    DK090500
       IF(TPL -TM) 205,208,208                                         DK090510
 205   TPL =TM                                                         DK090520
 208   ALTI=DEE-RP                                                     DK090530
       CPHI=COS(PHIR)                                                  DK090540
       SPHI=SIN(PHIR)                                                  DK090550
C          IF SATELLITE IS ORIENTED, FIND PHIC,COSRS,SIN AND COS LAMDA DK090560
       IF(NORIEN) 281,3,281                                            DK090570
 281   SINLS=SPHI*CSIGMA-CPHI*SSIGMA                                   DK090580
       COSLS=-SPHI*SSIGMA-CPHI*CSIGMA                                  DK090590
       ANGS=ARCOS(CTHET)                                               DK090600
       ALT=3441.0*ALTI/RP                                              DK090610
       IF(NORIEN) 283,283,282                                          DK090620
 282   CFLS=1.0                                                        DK090630
       SFLS=0.0                                                        DK090640
       FLSC=COSLS                                                      DK090650
```

```
      FLSS=SINLS
      GO TO 2831
283   CFLS=COSLS
      SFLS=SINLS
      FLSC=1.0
      FLSS=0.0
2831  DO 287 K=1,NSATP
      IF(NORIEN) 2832,2838,2838
2832  COSE=COSLS*COSL(K)-SINLS*SINL(K)
      GAMM(K)=ARCOS(COSE)
2838  RNUM=COSL(K)*SFLS+SINL(K)*CFLS
      DEN=((SINB*SINLS)**2+COSB**2)*(COSO(K)**2+RNUM**2)
      RNUM=SINLS*SINB*RNUM+COSB*COSO(K)
      COSX=RNUM/SQRT(DEN)
      IF(COSX-1.0) 285,284,284
284   PHIT(K)=0.0
      GO TO 2861
285   IF(COSX+1.0) 2850,2850,286
2850  PHIT(K)=180.0
      GO TO 2861
286   PHIT(K)=ARCOS(COSX)
2861  IF(NORIEN) 287,287,2862
2862  COSRS(K)=SINB*(COSL(K)*FLSC+SINL(K)*FLSS)+COSB*COSO(K)
287   CONTINUE
3     TABS=TELAPS-TIMEZ+(RV-1.0)*PEE
      IF (TABS) 98,98,99
98    TABS=TABS+PEE
99    RETURN
      END


       FOR      DECK10,DECK10
      SUBROUTINE TEMPER(QSAT)
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),
     2GAMM(200),NDUTY(200)
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)
      DIMENSION BUFFER(8)
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF
      COMMON PHI1,PHI2,BUFFER
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,
     1COSRS,PHIT,GAMM
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,
     1DECLIN
      DIMENSION AA(6),AA1(6),P(6),P1(6)
      COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,
     1YNHAT,ENHATL,EMAG,DERROR,DTTEST
```

```
      J=JSAT                                                            DK100290
      DELTAT=TIME(J2)-TIME(J1)                                          DK100300
      TIME1 = TIME(J1)                                                  DK100310
      HORD=DTMAX**IORDER                                                DK100320
      CALL HEAT(J)                                                      DK100330
C     NEW LOGIC                                                         DK100340
      IFLAG = 1                                                         DK100350
      IF(QOLD-QNEW)60,50,60                                             DK100360
 60   QINT = QOLD                                                       DK100370
      TLEFT=TIME(J2)-TBREAK                                             DK100380
C **** THE FOLLOWING CARD WAS ADDED 2/4/65 AT THE REQUEST OF MRI ****   DK100390
      TLEFT=AMOD(TLEFT,PEE)                                             DK100400
      DELTAT=DELTAT-TLEFT                                               DK100410
      DELTAT=AMOD(DELTAT,PEE)                                           DK100420
      IFLAG = 2                                                         DK100430
      GO TO 51                                                          DK100440
 61   IFLAG = 1                                                         DK100450
      TIME1 = TIME1 + DELTAT                                            DK100460
      DELTAT = TLEFT                                                    DK100470
      DELTAT=AMOD(DELTAT,PEE)                                           DK100480
      T(J1,J) = TEMP                                                    DK100490
 50   QINT = QNEW                                                       DK100500
C     BEGIN OLD LOGIC                                                   DK100510
 51   TEMP=T(J1,J)                                                      DK100520
      C10=10.0                                                          DK100530
      Q2=SQRT(QNET+QINT)                                                DK100540
      Q4=SQRT(Q2)                                                       DK100550
      PF2=SQRT(-0.5*EPSIG2)                                             DK100560
      PF4=SQRT(PF2)                                                     DK100570
      DT1=C10/(RHRCP*(QNET+QINT+0.5*EPSIG2*TEMP**4))                    DK100580
      DT1=ABS(DT1)                                                      DK100590
      DT2=1.0/((Q2+PF2*TEMP**2)*(Q4+PF4*TEMP))                          DK100600
      DTTEST=AMIN1(DT1,DT2)                                             DK100610
      IF(DTTEST)52,52,53                                                DK100620
 52   DTTEST=.00001*PEE                                                 DK100630
 53   ISTEPS=DELTAT/DTTEST+.999                                         DK100640
      IF(ISTEPS)100,100,101                                             DK100650
 100  ISTEPS=1                                                          DK100660
 101  STEPS=ISTEPS                                                      DK100670
      STEP=DELTAT/STEPS                                                 DK100680
      THETA=STEP/DTMAX                                                  DK100690
      TEMP=T(J1,J)                                                      DK100700
      TIME2 = TIME1                                                     DK100710
      DO 30 I = 1,ISTEPS                                                DK100720
      F0 = PHIFN(TIME2,TEMP,STEP)                                       DK100730
      TEMP=TEMP+STEP*F0                                                 DK100740
      GO TO (1,1,3),IERROR                                              DK100750
 1    CALL ERROR(STEP,F0)                                               DK100760
      EN1=EN*HORD                                                       DK100770
      DERROR=(EN-EMAG)*HORD                                             DK100780
      EMAG=EN                                                           DK100790
      WRITE (6,601)EN1,DERROR,TEMP                                      DK100800
 601  FORMAT(5H0EN1=1PE14.7,5H   DE=E14.7,7H   TEMP=E14.7)              DK100810
 3    CONTINUE                                                          DK100820
 30   TIME2 = TIME2 + STEP                                              DK100830
C     NEW LOGIC                                                         DK100840
      GO TO (62,61),IFLAG                                               DK100850
C     BEGIN OLD LOGIC                                                   DK100860
 62   T(J2,J) = TEMP                                                    DK100870
 11   RETURN                                                            DK100880
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      END                                                               DK100890

       FOR      DECK11,DECK11                                           DK110000
      SUBROUTINE INIT                                                   DK110010
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),  DK110020
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                   DK110030
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),       DK110040
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),  DK110050
     2GAMM(200),NDUTY(200)                                              DK110060
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)         DK110070
      DIMENSION BUFFER(6)                                               DK110080
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,    DK110090
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                            DK110100
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV      DK110110
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,    DK110120
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                    DK110130
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                 DK110140
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN        DK110150
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2    DK110160
      COMMON EPIP4,EPSIG2,TM,FTM,SAS2,SRASH                             DK110170
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                             DK110180
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK       DK110190
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                         DK110200
      COMMON PHI1,PHI2,BUFFER,RV,NLINE                                  DK110210
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,    DK110220
     1COSRS,PHIT,GAMM                                                   DK110230
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY                                 DK110240
C                DETERMINE REFERENCE TIME                               DK110250
      PHI=PHIZ2                                                         DK110260
      RV=1.0                                                            DK110270
      CALL LOCUS                                                        DK110280
      TIMEZ=TIMEZ+TABS                                                  DK110290
      IF(SUN-2.0) 89,80,80                                              DK110300
   80 PHIN2=-10.0                                                       DK110310
      PHOT2=-10.0                                                       DK110320
      GO TO 100                                                         DK110330
   89 IF(NOFIND) 90,90,92                                               DK110340
C             SET UP SUN-SHADE TESTS FOR FIRST ORBIT                    DK110350
   90 IF (PHI1) 1,2,2                                                   DK110360
    1 PHI1=PHI1+TWOPI                                                   DK110370
    2 IF (PHI2) 3,4,4                                                   DK110380
    3 PHI2=PHI2+TWOPI                                                   DK110390
    4 DIF=PHI1-PHI2                                                     DK110400
      IF (ABS(DIF)-PI) 8,8,5                                            DK110410
    5 IF (DIF) 6,9,9                                                    DK110420
    6 PHI2=PHI2-TWOPI                                                   DK110430
C           INTERCHANGE PHI1 AND PHI2                                   DK110440
    7 RUB=PHI1                                                          DK110450
      PHI1=PHI2                                                         DK110460
      PHI2=RUB                                                          DK110470
      GO TO 10                                                          DK110480
    8 IF (DIF) 10,10,7                                                  DK110490
    9 PHI1=PHI1-TWOPI                                                   DK110500
   10 T1=PHI1-PHIZ                                                      DK110510
      T2=PHI2-PHIZ                                                      DK110520
      IF (T1) 11,11,13                                                  DK110530
   11 IF (T2) 12,12,97                                                  DK110540
   12 T1=T1+TWOPI                                                       DK110550
      T2=T2+TWOPI                                                       DK110560
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      IF (T1) 14,14,13                                                  DK110570
   13 IF (T2) 97,97,98                                                  DK110580
   14 IF (T2) 98,98,97                                                  DK110590
C              ORBIT BEGINS IN SHADE                                    DK110600
   97 SUN=0.0                                                           DK110610
      GO TO 99                                                          DK110620
C              ORBIT BEGINS IN SUN                                      DK110630
   98 SUN=1.0                                                           DK110640
   99 PHI1=PHIZ+T1                                                      DK110650
      PHI2=PHIZ+T2                                                      DK110660
      PHIN2=PHI1/PI180                                                  DK110670
      PHOT2=PHI2/PI180                                                  DK110680
  100 RETURN                                                            DK110690
   92 SUN=1.0                                                           DK110700
      IF((PHOT2-PHIZ2)*(PHIZ2-PHIN2)) 100,100,93                        DK110710
   93 SUN=0.0                                                           DK110720
      GO TO 100                                                         DK110730
      END                                                               DK110740


       FOR      DECK12,DECK12                                           DK120000
      SUBROUTINE FIND                                                   DK120010
      DIMENSION X(3),Y(3),U(4),V(4)                                     DK120020
      EQUIVALENCE(X(1),TRASH(1)),(Y(1),TRASH(4)),(U(1),TRASH(7))        DK120030
      EQUIVALENCE(V(1),TRASH(11)),(C1,TRASH(15)),(C2,TRASH(16))         DK120040
      EQUIVALENCE(C3,TRASH(17))                                         DK120050
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),   DK120060
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                   DK120070
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),       DK120080
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),  DK120090
     2GAMM(200),NDUTY(200)                                              DK120100
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)         DK120110
      DIMENSION BUFFER(8)                                               DK120120
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,    DK120130
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                            DK120140
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV      DK120150
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,    DK120160
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                    DK120170
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                 DK120180
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN        DK120190
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DFE,DPSQ,J1,J2    DK120200
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH                             DK120210
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                             DK120220
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK       DK120230
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                         DK120240
      COMMON PHI1,PHI2,BUFFER                                           DK120250
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,    DK120260
     1COSRS,PHIT,GAMM                                                   DK120270
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY                                 DK120280
      DIMENSION KC(4)                                                   DK120290
      PHI1=-1000.0                                                      DK120300
      PHI2=-1000.0                                                      DK120310
C     PHI1 AND PHI2 =-1000 WILL SHOW THAT NO SUN-SHADE POINTS WERE FOUND DK120320
      XS1=0.0                                                           DK120330
      XS2=0.0                                                           DK120340
      YS1=0.0                                                           DK120350
      YS2=0.0                                                           DK120360
    1 SINSG=SSIGMA                                                      DK120370
      COSSG=CSIGMA                                                      DK120380
      IF(ABS(COSB)-.01) 2,2,12                                          DK120390
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C          SUN IS IN ORBITAL PLANE                                   DK120400
 2    CALL BETA90                                                    DK120410
      GO TO 99                                                       DK120420
C               SUN IS NOT IN ORBITAL PLANE                          DK120430
 12   D2=C2*A                                                        DK120440
      D1=C1*A*A                                                      DK120450
      D=C/A                                                          DK120460
      D31=C3-D1                                                      DK120470
      DT(1,1)=C3+C3                                                  DK120480
      DS=D2*D2                                                       DK120490
      DU=C3-1.0                                                      DK120500
      A4=D31*D31+DS                                                  DK120510
      A3=2.0*D*(DT(1,1)*D31+DS)                                      DK120520
      A2=D*D*(DT(1,1)*(DT(1,1)+D31)+DS)-2.0*DU*D31-DS                DK120530
      A1=D*DT(1,1)*(D*D*DT(1,1)-2.0*DU)                              DK120540
      A0=(DU-D*D*C3)**2                                              DK120550
C                  CALL ROUTINE TO FACTOR QUARTIC                    DK120560
      CALL QUART(A4,A3,A2,A1,A0)                                     DK120570
 37   KR=0                                                           DK120580
      SSHA1=0.0                                                      DK120590
      SSHA2=0.0                                                      DK120600
      JC=1                                                           DK120610
      DO 375 J=1,4                                                   DK120620
      IF(ABS(V(J))-.100) 371,375,375                                 DK120630
 371  KC(JC)=J                                                       DK120640
      JC=JC+1                                                        DK120650
 375  CONTINUE                                                       DK120660
      IF(JC-3) 99,376,380                                            DK120670
C        TWO REAL ROOTS,PUT THEM FIRST AND SECOND                    DK120680
 376  KK=2                                                           DK120690
      GO TO 39                                                       DK120700
C        FOUR REAL ROOTS, LOOK FOR A REPEATED ROOT                   DK120710
 380  DO 385 K=1,2                                                   DK120720
      KP=K+1                                                         DK120730
      DO 384 J=KP,4                                                  DK120740
      DIF=ABS(U(J)-U(K))-.001                                        DK120750
      IF(DIF) 381,384,384                                            DK120760
C         PUT REPEATED ROOTS TOGETHER, FIRST OR LAST PAIR            DK120770
C               TO AVOID TROUBLE IN GETTING CORRESPONDING Y          DK120780
 381  N=3-K                                                          DK120790
      RUB=U(N)                                                       DK120800
      CRASH=V(N)                                                     DK120810
      U(N)=U(J)                                                      DK120820
      V(N)=V(J)                                                      DK120830
      U(J)=RUB                                                       DK120840
      V(J)=CRASH                                                     DK120850
      GO TO 386                                                      DK120860
 384  CONTINUE                                                       DK120870
 385  CONTINUE                                                       DK120880
 386  KK=4                                                           DK120890
C            FIND VALUES OF Y CORRESPONDING TO EACH REAL X           DK120900
 39   J=1                                                            DK120910
 3907 K=KC(J)                                                        DK120920
 41   CALL WYE(U(1),K,Y1,P1,NP)                                      DK120930
 410  SS=P1-SIGMA                                                    DK120940
C               IS PHI A SUPERFLUOUS ROOT                            DK120950
      IF(COS(SS)) 42,60,60                                           DK120960
 42   IF(KR) 43,43,44                                                DK120970
C        FIRST  SUN-SHADE CHANGE POINT                               DK120980
 43   SSHA1=SS                                                       DK120990
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      PHI1=P1                                                           DK121000
      XS1=U(K)*A                                                        DK121010
      YS1=Y1*A                                                          DK121020
      KR=1                                                              DK121030
      GO TO 60                                                          DK121040
C        SECOND SUN-SHADE CHANGE POINT                                  DK121050
 44   SSHA2=SS                                                          DK121060
      PHI2=P1                                                           DK121070
      XS2=U(K)*A                                                        DK121080
      YS2=Y1*A                                                          DK121090
 45   KR=2                                                              DK121100
      GO TO 99                                                          DK121110
C                 IF X IS A REPEATED ROOT USE + AND - Y VALUES          DK121120
 60   IF(NP) 70,70,61                                                   DK121130
 61   NP=0                                                              DK121140
      J=J+1                                                             DK121150
      P1=-P1                                                            DK121160
      Y1=-Y1                                                            DK121170
      GO TO 410                                                         DK121180
 70   J=J+1                                                             DK121190
      IF(J-KK) 3907,3907,99                                             DK121200
 99   RETURN                                                            DK121210
      END                                                               DK121220

 FOR      DECK13,DECK13                                                 DK130000
      SUBROUTINE SUNOR(SL,CL,SO,CO,SB,CB,CD,GM,NO)                      DK130010
      COSLP=SO*CL                                                       DK130020
      SINLP=SO*SL                                                       DK130030
      IF(NO) 250,99,205                                                 DK130040
 205  GM=ARCOS(COSLP)                                                   DK130050
      GO TO 90                                                          DK130060
 250  CD=COSLP                                                          DK130070
      COSLP=SB*CD-CB*CO                                                 DK130080
      CO=CO*SB+CB*CD                                                    DK130090
 90   CL=COSLP                                                          DK130100
      SL=SINLP                                                          DK130110
 99   RETURN                                                            DK130120
      END                                                               DK130130

 FOR      DECK14,DECK14                                                 DK140000
      SUBROUTINE BETA90                                                 DK140010
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),   DK140020
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                   DK140030
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),       DK140040
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),  DK140050
     2GAMM(200),NDUTY(200)                                              DK140060
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)         DK140070
      DIMENSION BUFFER(8)                                               DK140080
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,    DK140090
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                            DK140100
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV      DK140110
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,    DK140120
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                    DK140130
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                 DK140140
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN        DK140150
      COMMON TIMEZ,TABS,IELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2    DK140160
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH                             DK140170
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                             DK140180
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      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK        DK140190
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                          DK140200
      COMMON PHI1,PHI2,BUFFER                                            DK140210
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,     DK140220
     1COSRS,PHIT,GAMM                                                    DK140230
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY                                  DK140240
      DIMENSION PAR(2),P(2)                                              DK140250
      PAR(1)=-1.0                                                        DK140260
      PAR(2)=1.0                                                         DK140270
      ARP=A*RP                                                           DK140280
      BRP=B*RP                                                           DK140290
      CRP=C*RP                                                           DK140300
      BB=B*B                                                             DK140310
      IF(CSIGMA) 20,1,20                                                 DK140320
1     DO 10 J=1,2                                                        DK140330
      CP=-ARP/(CRP+BB*PAR(J))                                            DK140340
      SP(1,1)=SQRT(1.0-CP**2)                                            DK140350
      IF(SSIGMA) 3,3,2                                                   DK140360
2     SP(1,1)=-SP(1,1)                                                   DK140370
3     TP=SP(1,1)/CP                                                      DK140380
      P(J)=ATAN(TP)                                                      DK140390
      IF(CP) 4,10,10                                                     DK140400
4     P(J)=P(J)+PI                                                       DK140410
10    CONTINUE                                                           DK140420
11    PHI1=P(1)                                                          DK140430
      PHI2=P(2)                                                          DK140440
99    RETURN                                                             DK140450
20    DO 40 J=1,2                                                        DK140460
      BSCR=BB*SSIGMA+PAR(J)*CRP                                          DK140470
      IF(BSCR) 28,21,28                                                  DK140480
21    SP(1,1)=ARP*PAR(J)/(BB*CSIGMA)                                     DK140490
      CP=SQRT(1.0-SP(1,1)**2)                                            DK140500
      IF(CP*CSIGMA+SP(1,1)*SSIGMA) 23,23,22                              DK140510
22    CP=-CP                                                             DK140520
23    IF(CP) 26,24,26                                                    DK140530
24    P(J)=0.5*PI                                                        DK140540
      IF(SP(1,1)) 25,40,40                                               DK140550
25    P(J)=1.5*PI                                                        DK140560
      GO TO 40                                                           DK140570
26    TP=SP(1,1)/CP                                                      DK140580
      P(J)=ATAN(TP)                                                      DK140590
      IF(CP) 27,40,40                                                    DK140600
27    P(J)=P(J)+PI                                                       DK140610
      GO TO 40                                                           DK140620
28    BS=-BB*CSIGMA                                                      DK140630
      CC=PAR(J)*ARP                                                      DK140640
      RUB=BS*BS+BSCR*BSCR                                                DK140650
      T1=-CC*BSCR/RUB                                                    DK140660
      T2=BS*SQRT(RUB-CC*CC)/RUB                                          DK140670
29    CP=T1+T2                                                           DK140680
      SP(1,1)=-(CP*BSCR+CC)/BS                                           DK140690
      IF(CP*CSIGMA+SP(1,1)*SSIGMA) 23,30,30                              DK140700
30    CP=T1-T2                                                           DK140710
      SP(1,1)=-(CP*BSCR+CC)/BS                                           DK140720
      GO TO 23                                                           DK140730
40    CONTINUE                                                           DK140740
      GO TO 11                                                           DK140750
      END                                                                DK140760
```

```
       FOR      DECK15,DECK15
      SUBROUTINE WYE(U,KK,Y1,P1,NP)
      DIMENSION X(3),Y(3),U(4),V(4)
      EQUIVALENCE(X(1),TRASH(1)),(Y(1),TRASH(4))
      EQUIVALENCE(V(1),TRASH(11)),(C1,TRASH(15)),(C2,TRASH(16))
      EQUIVALENCE(C3,TRASH(17))
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),
     2GAMM(200),NDUTY(41,8)
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)
      DIMENSION BUFFER(10)
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF
      COMMON BUFFER
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,
     1COSRS,PHIT,GAMM
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY
      X(1)=U(KK)
   50 BOA=B/A
      COA=C/A
      DISC=1.0-(X(1)+COA)**2
      IF(DISC+.0001) 90,2,2
    2 YDEN=2.0*SSIGMA*CSIGMA*(1.0-COSB**2)*X(1)
      IF(ABS(YDEN)-.0020) 3,4,4
C      NO UNIQUE Y FOR THIS X VALUE
    3 Y(1)=BOA*SQRT(DISC)
      NP=1
      GO TO 10
C          UNIQUE Y FOR THIS X VALUE
    4 YNUM=X(1)*X(1)*((COSB*CSIGMA)**2+SSIGMA**2)-(BEE/A)**2
      YNUM=YNUM+BOA*BOA*DISC*((COSB*SSIGMA)**2+CSIGMA**2)
      Y(1)=YNUM/YDEN
      NP=0
   10 IF(X(1)) 15,11,15
   11 PHI=1.57079365
      GO TO 20
   15 PHI=ATAN(Y(1)/X(1))
      IF(X(1)) 16,20,20
   16 PHI=PHI+3.1415927
   20 TORB=(Y(1)/BOA)**2-DISC
      IF(ABS(TORB)-.001) 21,21,90
   21 TSHADE=(COSB*(X(1)*CSIGMA+Y(1)*SSIGMA))**2+(X(1)*SSIGMA-Y(1)*CSIGM
     1A)**2
      TSHADE=(A/BEE)**2*TSHADE-1.0
      IF(ABS(TSHADE)-.001) 95,95,90
   90 P1=SIGMA
      GO TO 96
   95 P1=PHI
```

```
96    Y1=Y(1)                                                              DK150600
      RETURN                                                               DK150610
      END                                                                  DK150620

       FOR      DECK16,DECK16                                              DK160000
      SUBROUTINE SIGBET(KABG,LSHADE)                                       DK160010
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),     DK160020
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                      DK160030
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),         DK160040
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),    DK160050
     2GAMM(200),NDUTY(200)                                                DK160060
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)           DK160070
      DIMENSION BUFFER(8)                                                  DK160080
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,      DK160090
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                              DK160100
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV        DK160110
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,      DK160120
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                      DK160130
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                    DK160140
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN          DK160150
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2      DK160160
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH                               DK160170
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                                DK160180
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK         DK160190
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                           DK160200
      COMMON PHI1,PHI2,BUFFER                                              DK160210
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,      DK160220
     1COSRS,PHIT,GAMM                                                      DK160230
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,      DK160240
     1DECLIN                                                               DK160250
      EQUIVALENCE(TRASH(15),C1),(TRASH(16),C2),(TRASH(17),C3)             DK160260
C                 FIND SIGMA IF PART OF ORBIT MAY BE SHADED               DK160270
      SUN=1.0                                                              DK160280
      IF(KABG) 600,700,600                                                 DK160290
C          IF KABG IS 0, INPUT IS ALPHA, BETA, GAMMA                      DK160300
600   CW=COS(ASCNOD*PI180)                                                 DK160310
      SW=SIN(ASCNOD*PI180)                                                 DK160320
      SO=SIN(ASNLNG*PI180)                                                 DK160330
      CO=COS(ASNLNG*PI180)                                                 DK160340
      CI=COS(ANINCL*PI180)                                                 DK160350
      SI=SIN(ANINCL*PI180)                                                 DK160360
      SR=SIN(RGTASC*PI180)                                                 DK160370
      CR=COS(RGTASC*PI180)                                                 DK160380
      CD=COS(DECLIN*PI180)                                                 DK160390
      SD=SIN(DECLIN*PI180)                                                 DK160400
      COSA=((CW*CO-SW*SO*CI)*CR+SR*(CW*SO+SW*CO*CI))*CD+SW*SI*SD          DK160410
      ALP2=ARCOS(COSA)                                                     DK160420
      COSB=CD*SI*(SO*CR-CO*SR)+CI*SD                                       DK160430
      BET2=ARCOS(COSB)                                                     DK160440
      SINB=SIN(PI180*BET2)                                                 DK160450
      COSG=CD*(SR*(CO*CW*CI-SO*SW)-CR*(CW*SO*CI+SW*CO))+CW*SI*SD          DK160460
      GAM2=ARCOS(COSG)                                                     DK160470
700   IF(ABS(COSA)-.01) 701,710,710                                        DK160480
701   IF(ABS(COSG)-.01) 702,7020,7020                                      DK160490
7020  IF(COSG) 704,703,703                                                 DK160500
702   SUN=2.0                                                              DK160510
 **** THE FOLLOWING CARD WAS ADDED 12/15/66 TO ELIMINATE TERMINATOR       DK160520
       ORBIT PROBLEMS.                                              ****   DK160530
      SSIGMA=0.0                                                           DK160540
```

```
**** THE FOLLOWING CARD WAS ADDED 12/15/66 TO ELIMINATE TERMINATOR
       ORBIT PROBLEMS.                                               ****
      CSIGMA=1.0
      SIGMA=0.0
      GO TO 722
703   SIGMA=PIH
      SIGMA2=90.0
      SSIGMA=1.0
      GO TO 705
704   SIGMA=1.5*PI
      SIGMA2=270.0
      SSIGMA=-1.0
705   CSIGMA=0.0
      TSIGMA=SSIGMA*1.E 20
      GO TO 722
710   IF(ABS(COSG)-.01) 711,715,715
711   IF (COSA) 713,712,712
712   SIGMA=0.0
      CSIGMA=1.0
      GO TO 714
713   SIGMA=PI
      CSIGMA=-1.0
714   SSIGMA=0.0
      TSIGMA=0.0
      GO TO 722
715   CSIGMA=COSA/SQRT(COSA**2+COSG**2)
      SSIGMA=SQRT(1.0-CSIGMA**2)
      IF(COSG) 716,717,717
716   SSIGMA=-SSIGMA
717   CALL DVCHK (K000FX)
       GO TO(7171,7171),K000FX
7171  TSIGMA=SSIGMA/CSIGMA
      CALL DVCHK (K000FX)
       GO TO(703,718),K000FX
718   SIGMA=ATAN(TSIGMA)
      IF (CSIGMA) 719,720,720
719   SIGMA=SIGMA+PI
720   IF (SIGMA) 721,722,722
721   SIGMA=SIGMA+PI+PI
722   IF(NORIEN) 723,209,723
723   DO 725 J=1,NSATP
      CALL SUNOR(SINL(J),COSL(J),SINO(J),COSO(J),SINB,COSB,COSRS(J),
     1GAMM(J),NORIEN)
725   CONTINUE
                 FIND INTERSECTION OF ELLIPSES
209   IF(SUN-2.0) 210,199,199
210   IF(ABS(COSB)-.01) 1001,211,211
211   AYE=ABS(RP/COSB)
      BEE=RP
      BEESQ=BEE*BEE
      C1=((CSIGMA*COSB)**2+SSIGMA**2)/BEESQ
      C2=(COSB*COSB-1.0)*2.0*B*SSIGMA*CSIGMA/BEESQ
      C3=((SSIGMA*COSB)**2+CSIGMA**2)*(B/BEE)**2
1001  IF(LSHADE) 199,1002,199
1002  CALL FIND
199   CONTINUE
      CALL INIT
      RETURN
      END
```

```
      FOR       DECK17,DECK17
      SUBROUTINE INTERP(PROP,TEMP,JX,ANS)
C          PROP IS EEE(EPSILON),RO(RHO), OR SP(SPEC. HEAT)
C               TEMP IS TEMPERATURE OF ELEMENT
C        JX IS INDEX INDICATING WHICH COATING TABLE TO USE-OR SUBSTRATE
C          ANS IS EPSILON, RHO, OR CP - RESPECTIVELY
      DIMENSION PROP(8,42)
      DO 16 I=1,42,2
 1    IF(TEMP-PROP(JX,I))11,13,12
 1    IF(TEMP-PROP(JX,I+2))16,14,15
 2    IF(TEMP-PROP(JX,I+2))15,14,16
 3    ANS=PROP(JX,I+1)
      RETURN
 4    ANS=PROP(JX,I+3)
      RETURN
 5    ANS=PROP(JX,I+1)+((PROP(JX,I+3)-PROP(JX,I+1))*
     1(TEMP-PROP(JX,I)))/(PROP(JX,I+2)-PROP(JX,I))
      RETURN
 6    CONTINUE
      RETURN
      END


      FOR       DECK18,DECK18
      SUBROUTINE ARROUT(A,L8,NSATP)
      DIMENSION A(200)
 1    DO 20 J=1,L8
      I4=10*J-9
      NF=MINO(I4+9,NSATP)
 )    WRITE (6,705)I4,(A(K),K=I4,NF)
 )5   FORMAT(14XI4,2X10F10.2)
 99   RETURN
      END


      FOR       DECK19,DECK19
      FUNCTION ARCOS(C)
      IF(C) 3,2,3
      ARCOS=90.0
 9    RETURN
 3    ARCOS=ATAN(SQRT((1.0/C)**2-1.0))/.017453293
      IF(C) 4,99,99
 4    ARCOS=180.0-ARCOS
      GO TO 99
      END


      FOR       DECK20,DECK20
      SUBROUTINE QUART  (A4,A3,A2,A1,A0)
      DIMENSION X(3),Y(3),U(4),V(4)
      COMMON X,Y,U,V
      DIMENSION SC(8)
      SC(1)=A4
      SC(2)=A3
      SC(3)=A2
      SC(4)=A1
      SC(5)=A0
      CALL DDFERI(SC(1))
      DO 5 J=1,4
```

```
      K=J+J                                                             DK200120
      U(J)=SC(K-1)                                                      DK200130
5     V(J)=SC(K)                                                        DK200140
9     RETURN                                                            DK200150
      END                                                               DK200160


 FOR      DECK21,DECK21                                                 DK210000
      FUNCTION PHIFN(XN,YN,STEP)                                        DK210010
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),   DK210020
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                   DK210030
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),       DK210040
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),  DK210050
     2GAMM(200),NDUTY(200)                                              DK210060
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)         DK210070
      DIMENSION BUFFER(8)                                               DK210080
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,    DK210090
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                            DK210100
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV      DK210110
      COMMON A,B,C,AYF,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,    DK210120
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                    DK210130
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                 DK210140
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN        DK210150
      COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2    DK210160
      COMMON EPTP4,EPSIG2,TM,FTM,SAS2,SRASH                             DK210170
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                             DK210180
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK       DK210190
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                         DK210200
      COMMON PHI1,PHI2,BUFFER                                           DK210210
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,    DK210220
     1COSRS,PHIT,GAMM                                                   DK210230
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,    DK210240
     1DECLIN                                                            DK210250
      DIMENSION AA(6),AA1(6),P(6),P1(6)                                 DK210260
      COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,   DK210270
     1YNHAT,ENHATL,EMAG,DERROR,DTTEST                                   DK210280
      ARGX=XN                                                           DK210290
      ARGY=YN                                                           DK210300
      PHIFN = 0.0                                                       DK210310
      NU=1                                                              DK210320
   10 FNK=FOFXY(ARGX,ARGY)                                              DK210330
      PHIFN=PHIFN+AA(NU)*FNK                                            DK210340
      IF(NU-IORDER)11,12,12                                             DK210350
11    NU=NU+1                                                           DK210360
      RASH=P(NU)*STEP                                                   DK210370
      ARGX=XN+RASH                                                      DK210380
      ARGY=YN+RASH*FNK                                                  DK210390
      GO TO 10                                                          DK210400
12    RETURN                                                            DK210410
      END                                                               DK210420


 FOR      DECK22,DECK22                                                 DK220000
      FUNCTION GFN(X,Y)                                                 DK220010
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),   DK220020
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                   DK220030
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),       DK220040
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),  DK220050
     2GAMM(200),NDUTY(200)                                              DK220060
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)         DK220070
```

```
 DIMENSION BUFFER(8)                                                    DK220080
 COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,         DK220090
1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                                 DK220100
 COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV           DK220110
 COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,         DK220120
1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                         DK220130
 COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                      DK220140
 COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN             DK220150
 COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2         DK220160
 COMMON EPIP4,EPSIG2,TM,FTM,SAS2,SRASH                                  DK220170
 COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                                  DK220180
 COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK            DK220190
 COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                              DK220200
 COMMON PHI1,PHI2,BUFFER                                                DK220210
 COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,         DK220220
1COSRS,PHIT,GAMM                                                        DK220230
 COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,         DK220240
1DECLIN                                                                 DK220250
 DIMENSION AA(6),AA1(6),P(6),P1(6)                                      DK220260
 COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,        DK220270
1YNHAT,ENHATL,EMAG,DERROR,DTTEST                                        DK220280
 GFN=2.0*EPSIG2*Y**3                                                    DK220290
 RETURN                                                                 DK220300
 END                                                                    DK220310
```

```
  FOR      DECK23,DECK23                                                DK230000
 FUNCTION FOFXY(X,Y)                                                    DK230010
 DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),        DK230020
1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                        DK230030
 DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),            DK230040
1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),       DK230050
2GAMM(200),NDUTY(200)                                                   DK230060
 DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)              DK230070
 DIMENSION BUFFER(8)                                                    DK230080
 COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,         DK230090
1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                                 DK230100
 COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV           DK230110
 COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,         DK230120
1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                         DK230130
 COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                      DK230140
 COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN             DK230150
 COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2         DK230160
 COMMON EPIP4,EPSIG2,TM,FTM,SAS2,SRASH                                  DK230170
 COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                                  DK230180
 COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK            DK230190
 COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                              DK230200
 COMMON PHI1,PHI2,BUFFER                                                DK230210
 COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,         DK230220
1COSRS,PHIT,GAMM                                                        DK230230
 COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,         DK230240
1DECLIN                                                                 DK230250
 DIMENSION AA(6),AA1(6),P(6),P1(6)                                      DK230260
 COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,        DK230270
1YNHAT,ENHATL,EMAG,DERROR,DTTEST                                        DK230280
 FOFXY=RHRCP*(QNET+QINT+0.5*EPSIG2*Y**4)                                DK230290
 RETURN                                                                 DK230300
 END                                                                    DK230310
```

```
 FOR       DECK24,DECK24                                                DK240000
 FUNCTION DELTA(XN,YN,STEP,F0)                                          DK240010
 DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),       DK240020
1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                        DK240030
 DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),           DK240040
1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),      DK240050
2GAMM(200),NDUTY(200)                                                   DK240060
 DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)              DK240070
 DIMENSION BUFFER(8)                                                    DK240080
 COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,         DK240090
1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                                 DK240100
 COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV           DK240110
 COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,         DK240120
1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                         DK240130
 COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                      DK240140
 COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN             DK240150
 COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2         DK240160
 COMMON EPIP4,EPSIG2,TM,FTM,SAS2,SRASH                                  DK240170
 COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                                  DK240180
 COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK            DK240190
 COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                              DK240200
 COMMON PHI1,PHI2,BUFFER                                                DK240210
 COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,         DK240220
1COSRS,PHIT,GAMM                                                        DK240230
 COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,         DK240240
1DECLIN                                                                 DK240250
 DIMENSION AA(6),AA1(6),P(6),P1(6)                                      DK240260
 COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,        DK240270
1YNHAT,ENHATL,EMAG,DERROR,DTTEST                                        DK240280
 STEP1=STEP*0.5                                                         DK240290
 F1=PHIFN(XN,YN,STEP1)                                                  DK240300
 XN1=XN+STEP1                                                           DK240310
 YN1=YN+STEP1*F1                                                        DK240320
 F2=PHIFN(XN1,YN1,STEP1)                                                DK240330
 DELTA=STEP1*(F1+F2)-F0*STEP                                            DK240340
 RETURN                                                                 DK240350
 END                                                                    DK240360
```

```
 FOR       DECK25,DECK25                                                DK250000
 SUBROUTINE ERROR(STEP,F0)                                              DK250010
 DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),       DK250020
1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                        DK250030
 DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),           DK250040
1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),      DK250050
2GAMM(200),NDUTY(200)                                                   DK250060
 DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)              DK250070
 DIMENSION BUFFER(8)                                                    DK250080
 COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,         DK250090
1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                                 DK250100
 COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV           DK250110
 COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,         DK250120
1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                         DK250130
 COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                      DK250140
 COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN             DK250150
 COMMON TIMEZ,TABS,TELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2         DK250160
 COMMON EPIP4,EPSIG2,TM,FTM,SAS2,SRASH                                  DK250170
 COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                                  DK250180
 COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK            DK250190
 COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                              DK250200
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```
      COMMON PHI1,PHI2,BUFFER                                                DK250210
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,         DK250220
     1COSRS,PHIT,GAMM                                                        DK250230
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,         DK250240
     1DECLIN                                                                 DK250250
      DIMENSION AA(6),AA1(6),P(6),P1(6)                                      DK250260
      COMMON AA,AA1,P,P1,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,        DK250270
     1YNHAT,ENHATL,EMAG,DERROR,DTTEST                                        DK250280
      TLAST=TIME(J1)                                                         DK250290
      TJ=T(J1,1)                                                             DK250300
      DTIME=STEP                                                             DK250310
C     HENRICI ERROR FUNCTION.                                                DK250320
      GO TO (1,1,3),IERROR                                                   DK250330
 1    DEL=DELTA(TLAST,TJ,STEP,F0)                                            DK250340
 2    DERROR = -((THETA/DTMAX)**IORDER)*DEL*FACT*THETA                       DK250350
      EN=EN*(1.0+DTIME*GFN(TLAST,TJ))+DERROR                                 DK250360
 3    RETURN                                                                 DK250370
      END                                                                    DK250380


*      FOR      DECK26,DECK26                                                DK260000
      SUBROUTINE GEOFAC(FAC)                                                 DK260010
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),        DK260020
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TIME(2)                        DK260030
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),            DK260040
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),       DK260050
     2GAMM(200),NDUTY(200)                                                   DK260060
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)              DK260070
      DIMENSION BUFFER(10)                                                   DK260080
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,         DK260085
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                                 DK260090
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV           DK260100
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,O,CAY,BARL,W,ALP2,BET2,GAM2,         DK260110
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                         DK260120
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                      DK260130
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHOT2,SUN             DK260140
      COMMON TIMEZ,TABS,IELAPS,ZEIT,TIME,DELTAT,XP,YP,DEE,DPSQ,J1,J2         DK260150
      COMMON EPIP4,EPSIG2,TM,FTM,SAS2,SRASH                                  DK260160
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                                  DK260170
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK            DK260180
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                              DK260190
      COMMON BUFFER                                                          DK260200
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,         DK260210
     1COSRS,PHIT,GAMM                                                        DK260220
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,         DK260230
     1DECLIN                                                                 DK260240
      DIMENSION R(8),Q(4),P(2),S(2)                                          DK260250
      GAM30=GAM/30.0                                                         DK260260
      NG30=GAM30                                                             DK260270
      GN30=NG30                                                              DK260280
      GF=GAM30-GN30                                                          DK260290
 5    P30=PHIC/30.0                                                          DK260300
      NP30=P30                                                               DK260310
      PN30=NP30                                                              DK260320
      PF=P30-PN30                                                            DK260330
      IF(NP30-6) 6,4,4                                                       DK260340
 4    NP30=5                                                                 DK260350
      PF=1.0                                                                 DK260360
 6    NP51=7*NG30+NP30+1                                                     DK260370
C             IF TABLES FOR ZERO H ARE USED, DO J=2,9                        DK260380
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      DO 10 J=3,9                                                       DK260390
      NH=J-1                                                            DK260400
      IF(HTAB(J)-ALT) 10,7,7                                            DK260410
10    CONTINUE                                                          DK260420
7     HF=(ALT-HTAB(NH))/(HTAB(NH+1)-HTAB(NH))                           DK260430
11    DO 13 J=2,10                                                      DK260440
      ANGD=ANGS                                                         DK260450
      NA=J-1                                                            DK260460
      IF(ANGTAB(J)-ANGD) 13,12,12                                       DK260470
13    CONTINUE                                                          DK260480
12    AF=(ANGD-ANGTAB(NA))/(ANGTAB(NA+1)-ANGTAB(NA))                    DK260490
14    DO 25 JJ=1,2                                                      DK260500
      N=JJ-1                                                            DK260510
      K=NPS1+7*N                                                        DK260520
      DO 15 L=1,2                                                       DK260530
      KL=K+L-1                                                          DK260540
      LM=(L-1)*4                                                        DK260550
      R(LM+1)=F(NA,NH,KL)                                               DK260560
      R(LM+2)=F(NA,NH+1,KL)                                             DK260570
      R(LM+3)=F(NA+1,NH,KL)                                             DK260580
15    R(LM+4)=F(NA+1,NH+1,KL)                                           DK260590
      DO 18 J=1,4                                                       DK260600
      K=J+J                                                             DK260610
18    Q(J)=R(K-1)+HF*(R(K)-R(K-1))                                      DK260620
      DO 20 J=1,2                                                       DK260630
      K=J+J                                                             DK260640
20    P(J)=Q(K-1)+AF*(Q(K)-Q(K-1))                                      DK260650
      S(JJ)=P(1)+PF*(P(2)-P(1))                                         DK260660
      IF(NPS1-35) 25,22,22                                              DK260670
22    S(2)=0.0                                                          DK260680
      GO TO 26                                                          DK260690
25    CONTINUE                                                          DK260700
26    FAC=S(1)+GF*(S(2)-S(1))                                           DK260710
      IF(ALT-HTAB(9)) 27,27,98                                          DK260720
27    IF(COS(ANGS*PI180)+.6428) 98,98,99                                DK260730
99    IF(FAC) 98,100,100                                                DK260740
100   IF(1.0-FAC) 998,999,999                                           DK260750
98    FAC=0.0                                                           DK260760
      GO TO 999                                                         DK260770
998   FAC=1.0                                                           DK260780
999   RETURN                                                            DK260790
      END                                                               DK260800


       FOR      DECK27,DECK27                                           DK270000
      SUBROUTINE QIN(KK,LL,W)                                           DK270010
      DIMENSION TQINT(41,8),TRASH(7818),W(7)                            DK270020
      COMMON TRASH,TQINT                                                DK270030
      L=LL                                                              DK270040
      K=KK                                                              DK270050
      IF(L) 61,61,62                                                    DK270060
C           IF L=0, TABLE ENTRIES ARE CLEARED                           DK270070
61    TQINT(1,K)=0.0                                                    DK270080
      TQINT(41,K)=.0                                                    DK270090
      GO TO 99                                                          DK270100
62    TQINT(41,K)=2.0                                                   DK270110
      DO 63 J=1,7                                                       DK270120
63    TQINT(J,K)=W(J)                                                   DK270130
C                IF L=1,2 OR 3, NO MORE CARDS ARE READ                  DK270140
C           IF L IS LARGER, READ MORE CARDS                             DK270150
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      IF(3-L) 64,99,99                                                  DK270160
   64 READ(5,65) (TQINT(2*J,K),TQINT(2*J+1,K),J=4,L)                    DK270170
 99   TQINT(2*L+2,K)=100000000.0                                        DK270180
      WRITE (11)K,L,(TQINT(J,K),J=1,41)                                 DK270190
      RETURN                                                            DK270200
 65   FORMAT(2X6F8.2,2F15.2)                                            DK270210
      END                                                               DK270220


*      FOR      DECK28,DECK28                                           DK280000
      SUBROUTINE DDVETA (C, RT, MTYPE)                                  DK280010
      DIMENSION C(4), RT(3), X(2)                                       DK280020
C THE FOLLOWING STATEMENT(S) HAVE BEEN MANUFACTURED BY THE TRANSLATOR---DK280030
C                                                                       DK280040
      DOUBLE PRECISION  C        , RT      , X       , A       , B      DK280050
      DOUBLE PRECISION  Q        , R       , DSQRT   , CORECT           DK280060
      DOUBLE PRECISION  PHI1     , DATAN2  , POD     , EXPO    , DLOG   DK280070
      DOUBLE PRECISION  DEXP     , DCOS    , DSIN    , CLOD    , PLOD   DK280080
      DO 10 L=2,4                                                       DK280090
   10 C(L)=C(L)/C(1)                                                    DK280100
      A=(3.0D0*C(3)-C(2)**2)/3.0D0                                      DK280110
      B=(2.0D0*(C(2))**3-9.0D0*C(2)*C(3)+27.0D0*C(4))/27.0D0            DK280120
      Q=B**2/4.0D0+A**3/27.0D0                                          DK280130
      IF (B) 600, 700, 600                                              DK280140
  700 IF (ABS(A)-.001) 12, 12, 300                                      DK280150
  600 IF(ABS(Q)-10.0**(-15)*B**2/4.0) 12, 300, 300                      DK280160
  300 IF (Q) 11, 12, 13                                                 DK280170
   12 MTYPE=0                                                           DK280180
      GO TO 14                                                          DK280190
   13 MTYPE=1                                                           DK280200
      GO TO 15                                                          DK280210
   11 MTYPE=-1                                                          DK280220
      Q  =DABS(Q)                                                       DK280230
      R  =DSQRT(Q)                                                      DK280240
      CORECT=-B/2.0D0                                                   DK280250
      PHI1=DATAN2(R,CORECT)/3.0D0                                       DK280260
      POD =DSQRT(B**2/4.0D0+Q)                                          DK280270
      IF (POD) 73, 70, 73                                               DK280280
   70 X(1)=0.0D0                                                        DK280290
      X(2)=0.0D0                                                        DK280300
      GO TO 17                                                          DK280310
   73 EXPO=(DLOG(POD))/3.0D0                                            DK280320
      POD=DEXP(EXPO)                                                    DK280330
      X(1)=     POD*DCOS(PHI1)                                          DK280340
      X(2)=     POD*DSIN(PHI1)                                          DK280350
      GO TO 17                                                          DK280360
   14 POD=-B/2.0D0                                                      DK280370
      IF (POD) 83, 80, 83                                               DK280380
   80 X(1)=0.0D0                                                        DK280390
      GO TO 84                                                          DK280400
   83 EXPO=(DLOG(DABS(POD)))/3.0D0                                      DK280410
      X(1)=(POD /DABS(POD))*DEXP(EXPO)                                  DK280420
   84 RT(1)=2.0D0*X(1)                                                  DK280430
      RT(2)=-X(1)                                                       DK280440
      RT(3)=RT(2)                                                       DK280450
      GO TO 199                                                         DK280460
   15 Q=DSQRT(Q)                                                        DK280470
      CLOD=-B/2.0D0+Q                                                   DK280480
      PLOD=CLOD-2.0D0*Q                                                 DK280490
      IF (CLOD) 96, 95, 96                                              DK280500
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   95 X(1)=0.0D0                                                        DK280510
      GO TO 97                                                          DK280520
   96 EXPO=(DLOG(DABS(CLOD)))/3.0D0                                     DK280530
      X(1)=(CLOD/DABS(CLOD))*DEXP(EXPO)                                 DK280540
   97 IF (PLOD) 91, 90, 91                                              DK280550
   90 X(2)=0.0D0                                                        DK280560
      GO TO 16                                                          DK280570
   91 EXPO=(DLOG(DABS(PLOD)))/3.0D0                                     DK280580
      X(2)=(PLOD/DABS(PLOD))*DEXP(EXPO)                                 DK280590
   16 RT(1)=X(1)+X(2)-C(2)/3.0D0                                        DK280600
      RT(2)=-.50D0*(X(1)+X(2))-C(2)/3.0D0                               DK280610
      RT(3)=     .86602540378443850D0*(X(1)-X(2))                       DK280620
      RETURN                                                            DK280630
   17 RT(1)=2.0D0*X(1)                                                  DK280640
      RT(2)=-X(1)+X(2)*1.7320508075688770D0                             DK280650
      RT(3)=-X(1)-X(2)*1.7320508075688770D0                             DK280660
  199 DO 200 L=1,3                                                      DK280670
  200 RT(L)=RT(L)-C(2)/3.0D0                                            DK280680
   18 RETURN                                                            DK280690
      END                                                               DK280700


       FOR      DECK29,DECK29                                           DK290000
      SUBROUTINE DDFER1 (SC)                                            DK290010
      DIMENSION C(8), A(4), Y(3)                                        DK290020
      DIMENSION SC(8)                                                   DK290030
C THE FOLLOWING STATEMENT(S) HAVE BEEN MANUFACTURED BY THE TRANSLATOR---DK290040
C                                                                       DK290050
      DOUBLE PRECISION  C       , A       , Y       , CLOD    , PLOD    DK290060
      DOUBLE PRECISION  P       , Q       , R       , U                 DK290070
      DOUBLE PRECISION  BIGA    , DSQRT   , DISC1   , DISC2   , ABSZ    DK290080
      DOUBLE PRECISION  CORECT  , PHI     , DATAN2  , DCOS    , DSIN    DK290090
      DOUBLE PRECISION  ZAP     , ZSQRE1  , ZSQRE2                      DK290100
C     DIMENSION C(8), A(4), Y(3)                                        DK290110
C     DIMENSION SC(8)                                                   DK290120
      DO 400 L=1,5                                                      DK290130
  400 C(L)=SC(L)                                                        DK290140
      DO 401 L=9,16                                                     DK290150
  401 C(L)=0.0                                                          DK290160
      A(1)=1.0D0                                                        DK290170
      CLOD=.250D0*C(2)/C(1)                                             DK290180
   14 IF (C(2)) 100, 101, 100                                           DK290190
  100 PLOD=C(1)**2                                                      DK290200
      P=C(3)/C(1)-.375D0*(C(2)**2)/PLOD                                 DK290210
      Q=C(4)/C(1)-.5D0*(C(3)*C(2))/(PLOD    )+.125D0*((C(2)/C(1))**3)   DK290220
      R=((C(2)**2)*C(3))/(16.0D0*(C(1)**3))-(3.0D0*(C(2)**4))/(256.0D0*(DK290230
     1C(1)    **4))-.25D0*(C(4)*C(2))/PLOD+C(5)/C(1)                    DK290240
  102 A(2)=-P                                                           DK290250
      A(3)=-4.0D0*R                                                     DK290260
      A(4)=4.0D0*P*R-Q**2                                               DK290270
      CALL DDVETA (A,Y, MTYPE)                                          DK290280
      IF (MTYPE) 15, 15, 16                                             DK290290
   15 U=Y(1)                                                            DK290300
      DO 666 L=2,3                                                      DK290310
      IF (U-Y(L))   76, 666, 666                                        DK290320
   76 U=Y(L)                                                            DK290330
  666 CONTINUE                                                          DK290340
      GO TO 21                                                          DK290350
   16 IF (Y(2)) 270, 271, 270                                           DK290360
  271 IF(ABS(Y(3))-10.0**(-7)) 272, 17, 17                              DK290370
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272 Y(2) = 0.0D0                                                        DK290380
    Y(3)=0.0D0                                                          DK290390
    GO TO 15                                                            DK290400
270 PLOD = DABS(Y(3)/Y(2))-5.0D-7                                       DK290410
    IF (PLOD) 18, 18, 17                                                DK290420
 17 U=Y(1)                                                              DK290430
    GO TO 21                                                            DK290440
 18 PLOD=Y(1)-Y(2)                                                      DK290450
    IF (PLOD) 20, 17, 17                                                DK290460
 20 U=Y(2)                                                              DK290470
 21 PLOD=U-P                                                            DK290480
    IF (ABS(PLOD)-10.0**(-10)) 200, 150, 150                            DK290490
150 BIGA=DSQRT(PLOD)                                                    DK290500
    DISC1=BIGA**2-2.0D0*U+2.0D0*Q/BIGA                                  DK290510
    DISC2=DISC1-4.0D0*Q/BIGA                                            DK290520
    IF (ABS(DISC1)-10.0**(-15)) 204, 205, 205                           DK290530
204 DISC1=0.0D0                                                         DK290540
205 IF (DISC1) 24, 22, 23                                               DK290550
 22    C (2)=0.0D0                                                      DK290560
       C (1)=-.50D0*BIGA                                                DK290570
       C (3)=C(1)                                                       DK290580
       C (4)=0.0D0                                                      DK290590
    GO TO 25                                                            DK290600
 23 DISC1=DSQRT(DISC1)                                                  DK290610
       C (1)=.50D0*(DISC1-BIGA)                                         DK290620
       C (2)=0.0D0                                                      DK290630
       C (4)=0.0D0                                                      DK290640
       C (3)=    C(1)-DISC1                                             DK290650
    GO TO 25                                                            DK290660
 24     C(1)=-.50D0*BIGA                                                DK290670
       C (3)=  C (1)                                                    DK290680
    PLOD=DABS(DISC1)                                                    DK290690
    C(2)    =.50D0*DSQRT(PLOD)                                          DK290700
    C(4)=-C(2)                                                          DK290710
 25 IF(ABS(DISC2)-10.0**(-15)) 210, 211, 211                            DK290720
210 DISC2=0.0D0                                                         DK290730
211 IF (DISC2) 28, 26, 27                                               DK290740
 26    C (6)=0.0D0                                                      DK290750
       C (8)=  C (6)                                                    DK290760
       C (5)=.50D0*BIGA                                                 DK290770
       C (7)=  C (5)                                                    DK290780
    GO TO 29                                                            DK290790
 27 DISC2=DSQRT(DISC2)                                                  DK290800
       C (6)=0.0D0                                                      DK290810
       C (5)=.50D0*(DISC2+BIGA)                                         DK290820
       C (8)=0.0D0                                                      DK290830
       C (7)=  C (5)-DISC2                                              DK290840
    GO TO 29                                                            DK290850
 28    C (5)=.50D0*BIGA                                                 DK290860
       C (7)=  C (5)                                                    DK290870
    PLOD=DABS(DISC2)                                                    DK290880
       C (6)=.50D0*DSQRT(PLOD)                                          DK290890
    C(8)=-C(6)                                                          DK290900
 29 DO 30  L=1,4                                                        DK290910
       C (2*L-1)=  C (2*L-1)-CLOD                                       DK290920
 30 CONTINUE                                                            DK290930
    DO 166 L=1,8                                                        DK290940
166 SC(L)=C(L)                                                          DK290950
    RETURN                                                              DK290960
101 P=C(3)     /C(1)                                                    DK290970
```

```
      Q=C(4)  /C(1)
      R=C(5) /C(1)
      GO TO 102
  200 PLOD=P**2-4.0D0*R
      IF (ABS(PLOD)-10.0**(-15)) 201, 202, 202
  201 PLOD=0.0D0
  202 IF (PLOD) 203, 300, 300
  203 ABSZ=DSQRT(P**2-PLOD)/2.0D0
      CORECT=-P
      PHI =DATAN2(DSQRT(-PLOD),CORECT)
      C(1)=ABSZ*DCOS(PHI)
      C(2)=ABSZ*DSIN(PHI)
      C(3)= C(1)
      C(4)=-C(2)
      C(5)=-C(1)
      C(6)= C(2)
      C(7)= C(5)
      C(8)=-C(2)
      GO TO 29
  300 ZAP=DSQRT(PLOD)
      ZSQRE1=.50D0*(-P+ZAP)
      ZSQRE2=ZSQRE1-ZAP
      IF (ZSQRE1) 301, 302, 302
  301 C(2)=DSQRT(-ZSQRE1)
      C(4)=-C(2)
      C(1)=0.0D0
      C(3)=0.0D0
      GO TO 310
  302 C(1)=DSQRT(ZSQRE1)
      C(3)=-C(1)
      C(2)=0.0D0
      C(4)=0.0D0
  310 IF (ZSQRE2) 303, 304, 304
  303 C(6)=DSQRT(-ZSQRE2)
      C(8)=-C(6)
      C(5)=0.0D0
      C(7)=0.0D0
      GO TO 29
  304 C(5)=DSQRT(ZSQRE2)
      C(7)=-C(5)
      C(6)=0.0D0
      C(8)=0.0D0
      GO TO 29
      END

       FOR      DECK30,DECK30
      SUBROUTINE TABLE(DATA,MX,MM)
C             MM IS NUMBER OF COATING MATERIALS( OR SUBSTRATE)
C             DATA IS RO FOR RHO, SP FOR SPEC. HEAT, AND EEE FOR EPSILON
C          MX=0    DESIGNATES  SUBSTRATE TABLE
C           MX=1  DESIGNATES  COATING TABLE
      DIMENSION DATA(8,42)
      M=MM
      K1=1
      KL=K1+5
  110 READ(5,201) (DATA(M,K),K=K1,KL),CODE1,CODE2
      IF(DATA(M,KL-5)-10000.0)111,115,115
 111  IF(DATA(M,KL-3)-10000.0)112,116,116
 112  IF(DATA(M,KL-1)-10000.0)113,117,117
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113   IF(KL-42)114,118,121                                                 DK300140
114   K1=K1+6                                                              DK300150
      KL=K1+5                                                              DK300160
      GO TO 110                                                            DK300170
115   DATA(M,42)=DATA(M,KL-4)                                              DK300180
      NK=KL-3                                                              DK300190
      GO TO 118                                                            DK300200
116   DATA(M,42)=DATA(M,KL-2)                                              DK300210
      NK=KL-1                                                              DK300220
      GO TO 118                                                            DK300230
117   DATA(M,42)=DATA(M,KL)                                                DK300240
      NK=KL+1                                                              DK300250
118   DATA(M,41)=10000.0                                                   DK300260
      IF(MX)121,119,120                                                    DK300270
119   WRITE (6,202)M,CODE1,CODE2                                           DK300280
      GO TO 122                                                            DK300290
120   WRITE (6,203)M,CODE1,CODE2                                           DK300300
      GO TO 122                                                            DK300310
121   WRITE (6,204)                                                        DK300320
122   CONTINUE                                                             DK300330
      WRITE (6,206)(DATA(M,J),J=1,NK)                                      DK300340
      RETURN                                                               DK300350
201   FORMAT(6E12.8,A6,A2)                                                 DK300360
202   FORMAT(20H0SUBSTRATE MATERIAL I2,4H IS A6,A2)                        DK300370
203   FORMAT(18H0COATING MATERIAL I2,4H IS A6,A2)                          DK300380
204   FORMAT(20H ERROR IN INPUT DATA)                                      DK300390
206   FORMAT(1P6E16.7)                                                     DK300400
      END                                                                  DK300410

*      FOR      DECK31,DECK31                                              DK310000
      SUBROUTINE MAIN2                                                     DK310010
CPLTP  IS THE MAIN PROGRAM OF LINK 2 (PLOT ROUTINES)                       DK310020
      DIMENSION TRASH(17),F(10,9,42),HTAB(9),ANGTAB(10),WH(18),XH(9),      DK310030
     1YH(6),ZH(6),ELL(9),RPP(9),RR(9),CAYY(9),TOME(2)                      DK310040
      DIMENSION DT(2,200),T(2,200),SINL(200),COSL(200),SINO(200),          DK310050
     1COSO(200),THICK(200),NCOAT(200),NSUBS(200),COSRS(200),PHIT(200),     DK310060
     2GAMM(200),NDUTY(200)                                                 DK310070
      DIMENSION ESUN(8),EEE(8,42),RO(8,42),SP(8,42),TQINT(41,8)            DK310080
      DIMENSION BUFFER(2)                                                  DK310090
      COMMON TRASH,F,HTAB,ANGTAB,WH,XH,YH,ZH,ELL,RPP,RR,CAYY,PI,PIH,       DK310100
     1TWOPI,PI180,NOFIND,NQORT,IFIRST,NEWSIG                               DK310110
      COMMON KPLNET,NORIEN,KTEMP,NUMRUN,NSATP,NPRINT,KREV,NP50,REV         DK310120
      COMMON A,B,C,AYE,BEE,RP,RN,PEE,EL,R,CAY,BARL,S,ALP2,BET2,GAM2,       DK310130
     1ALPHA2,BETA2,GAMMA2,COSA,COSB,COSG,SINB,PHIMAX                       DK310140
      COMMON SIGMA,CSIGMA,SSIGMA,TSIGMA                                    DK310150
      COMMON PHIZ2,DPHI2,PHIZ,DPHI,PHI,CPHI,SPHI,PHIN2,PHO12,SUN           DK310160
      COMMON TIMEZ,TABS,IELAPS,ZEIT,TOME,DELTAT,XP,YP,DEE,DPSQ,J1,J2       DK310170
      COMMON EPIP4,EPSIG2,TM,FTM,SAS2,SRASH                                DK310180
      COMMON G,RHRCP,RHO,CP,EPSLN,ITK,KITER                                DK310190
      COMMON QNET,QSAT,QINT,QEXT,QPLAN,QALB,QSUN,QOLD,QNEW,TBREAK          DK310200
      COMMON GAM,PHIC,ALT,ALTI,ANGS,CTHET,FD,FF                            DK310210
      COMMON PHI1,PHI2,ISIG,FUDGE,T4,JUDGE,BUFFER,RV,NLINE                 DK310220
      COMMON COSLS,SINLS,DT,T,SINL,COSL,SINO,COSO,THICK,NCOAT,NSUBS,       DK310230
     1COSRS,PHIT,GAMM                                                      DK310240
      COMMON ESUN,EEE,RO,SP,TQINT,NDUTY,ANINCL,ASCNOD,ASNLNG,RGTASC,       DK310250
     1DECLIN                                                               DK310260
      DIMENSION AA(6),AA1(6),P(6),PO(6)                                    DK310270
      COMMON AA,AA1,P,PO,IORDER,IORD1,IERROR,THETA,DTMAX,EN1,EN,FACT,      DK310280
     1YNHAT,ENHATL,EMAG,DERROR,DTTEST                                      DK310290
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      COMMON HSUN,HALB,HPLAN,NODE                                       DK310300
      DIMENSION HSUN(200),HALB(200),HPLAN(200),NODE(200)                DK310310
      COMMON KETCH                                                      DK310320
      COMMON HASUN,HAALB,HAPLN,HATOT                                    DK310330
      DIMENSION HASUN(200),HAALB(200),HAPLN(200),HATOT(200)             DK310340
      COMMON ZAREA                                                      DK310350
      DIMENSION ZAREA(200)                                              DK310360
      COMMON IMTHRU                                                     DK310370
      DIMENSION IMTHRU(200)                                             DK310380
      COMMON IMHI,PNAME,PHIPLT,TIMPLT,NPLOT,LAST,JUMP,LMAX,IONCF        DK310390
      DIMENSION PNAME(39),PHIPLT(190),TIMPLT(190)                       DK310400
      COMMON TYME1,TYME2,TYME                                           DK310410
      COMMON AG,      IN,J,KABG,KL,       K,LBJ,LL,LN,L,LSHADE,M,NCARD,   DK310420
     1NEWDC,NEWGAM,NEWMAT,NHEAD,N,NTRIG,PEE1,PG,PIN,POUT,ROP,SIGMA2      DK310430
      COMMON ELAMB,OMEGA,TKALT,TZ,W  ,AGNM,PGNM                         DK310440
      DIMENSION ELAMB(200),OMEGA(200),NZ(41),TKALT(9),TZ(200),W(7),Z(41)DK310450
      EQUIVALENCE(TRASH(15),C1),(TRASH(16),C2),(TRASH(17),C3)           DK310460
      EQUIVALENCE(TRASH(14),NBLANK),(Z(1),NZ(1))                        DK310470
      DIMENSION S1(190) ,S2(190),A1(190),A2(190),P1(190),P2(190),Q1(190)DK310480
     1,Q2(190),T1(190),T2(190),TX(1,200),PHIO(190)                      DK310490
      DIMENSION AS(200),BRITE(200),DARK(200),XLAMB(200),XMEGA(200)      DK310500
      DIMENSION THATS(16),ALL(20),FOLKS(13)                             DK310510
      COMMON/BLJK/IGO,JJ,KK,RUN,NFIRST,NALL,ALL1,NALL1                  DK310520
      CALL RESET                                                        DK310530
      NJ= 2*KPLNET                                                      DK310540
      NK= 3*(NORIEN+2)                                                  DK310550
      NL= 3*KTEMP +3                                                    DK310560
      THATS( 1)=ZH(1)                                                   DK310570
      THATS( 2)=WH(NJ-1)                                                DK310580
      THATS( 3)=WH(NJ)                                                  DK310590
      THATS( 4)=WH(4)                                                   DK310600
      THATS( 5)=ZH(2)                                                   DK310610
      THATS( 6)=ZH(3)                                                   DK310620
      THATS( 7)=XH(NK-2)                                                DK310630
      THATS( 8)=XH(NK-1)                                                DK310640
      THATS( 9)=XH(NK)                                                  DK310650
      THATS(10)=WH(4)                                                   DK310660
      THATS(11)=ZH(4)                                                   DK310670
      THATS(12)=ZH(5)                                                   DK310680
      THATS(13)=ZH(6)                                                   DK310690
      THATS(14)=YH(NL-2)                                                DK310700
      THATS(15)=YH(NL-1)                                                DK310710
      THATS(16)=YH(NL)                                                  DK310720
      CALL BINDEC (AGNM ,NALL1,ALL1,ADUM)                               DK310730
      ALL1=FOTA(ALL1)                                                   DK310740
      IF(NALL1-5)48,49,49                                               DK310750
   48 NALL1=NALL1+1                                                     DK310760
      DATA Q000HL/6H      =/                                            DK310770
   49 ALL( 1)=Q000HL                                                    DK310780
      DATA Q001HL/6HMAX(AL/                                             DK310790
      ALL( 2)=Q001HL                                                    DK310800
      DATA Q002HL/6HT)MIN=/                                             DK310810
      ALL( 3)=Q002HL                                                    DK310820
      CALL BINDEC (PGNM  ,NALL,ALL( 4),ADUM)                            DK310830
      ALL(4)=FOTA(ALL(4))                                               DK310840
      DATA Q003HL/6H PHIO=/                                             DK310850
      ALL( 5)=Q003HL                                                    DK310860
      CALL BINDEC (PHIZ2 ,NALL,ALL( 6),ADUM)                            DK310870
      ALL(6)=FOTA(ALL(6))                                               DK310880
      DATA Q004HL/6H DPHI=/                                             DK310890
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      ALL( 7)=Q004HL                                                    DK310900
      CALL BINDEC (DPHI2  ,NALL,ALL( 8),ADUM)                           DK310910
      ALL(8)=FDTA(ALL(8))                                               DK310920
      DATA Q005HL/6H SIGM=/                                             DK310930
      ALL( 9)=Q005HL                                                    DK310940
      CALL BINDEC (SIGMA2,NALL,ALL(10),ADUM)                            DK310950
      ALL(10)=FDTA(ALL(10))                                             DK310960
      DATA Q006HL/6H BETA=/                                             DK310970
      ALL(11)=Q006HL                                                    DK310980
      CALL BINDEC (BET2  ,NALL,ALL(12),ADUM)                            DK310990
      ALL(12)=FDTA(ALL(12))                                             DK311000
      DATA Q007HL/6H PHIN=/                                             DK311010
      ALL(13)=Q007HL                                                    DK311020
      CALL BINDEC (PIN   ,NALL,ALL(14),ADUM)                            DK311030
      ALL(14)=FDTA(ALL(14))                                             DK311040
      DATA Q008HL/6H POUT=/                                             DK311050
      ALL(15)=Q008HL                                                    DK311060
      CALL BINDEC (POUT  ,NALL,ALL(16),ADUM)                            DK311070
      ALL(16)=FDTA(ALL(16))                                             DK311080
      IF(KARG)65,60,65                                                  DK311090
      DATA Q009HL/6H ALPH=/                                             DK311100
   60 ALL(17)=Q009HL                                                    DK311110
      CALL BINDEC (ALP2  ,NALL,ALL(18),ADUM)                            DK311120
      ALL(18)=FDTA(ALL(18))                                             DK311130
      ALL(19)=Q010HL                                                    DK311140
      DATA Q010HL/6H GAMM=/                                             DK311150
      CALL BINDEC (GAM2  ,NALL,ALL(20),ADUM)                            DK311160
      ALL(20)=FDTA(ALL(20))                                             DK311170
      NALL=120                                                          DK311180
      GO TO 66                                                          DK311190
   65 NALL=96                                                           DK311200
      DATA Q011HL/6HINCL.=/                                             DK311210
      FOLKS( 1)=Q011HL                                                  DK311220
      CALL BINDEC(ANINCL,NF,FOLKS( 2),ADUM)                             DK311230
      FOLKS(2)=FDTA(FOLKS(2))                                           DK311240
      DATA Q012HL/6H ARG O/                                             DK311250
      FOLKS( 3)=Q012HL                                                  DK311260
      DATA Q013HL/6HF PER=/                                             DK311270
      FOLKS( 4)=Q013HL                                                  DK311280
      CALL BINDEC(ASCNOD,NF,FOLKS( 5),ADUM)                             DK311290
      FOLKS(5)=FDTA(FOLKS(5))                                           DK311300
      DATA Q014HL/6H LONG./                                             DK311310
      FOLKS( 6)=Q014HL                                                  DK311320
      DATA Q015HL/6HOF ASC/                                             DK311330
      FOLKS( 7)=Q015HL                                                  DK311340
      DATA Q016HL/6H NODE=/                                             DK311350
      FOLKS( 8)=Q016HL                                                  DK311360
      CALL BINDEC(ASNLNG,NF,FOLKS( 9),ADUM)                             DK311370
      FOLKS(9)=FDTA(FOLKS(9))                                           DK311380
      DATA Q017HL/6H  RA.=/                                             DK311390
      FOLKS(10)=Q017HL                                                  DK311400
      CALL BINDEC(RGTASC,NF,FOLKS(11),ADUM)                             DK311410
      FOLKS(11)=FDTA(FOLKS(11))                                         DK311420
      DATA Q018HL/6H DEC.=/                                             DK311430
      FOLKS(12)=Q018HL                                                  DK311440
      CALL BINDEC(DECLIN,NF,FOLKS(13),ADUM)                             DK311450
      FOLKS(13)=FDTA(FOLKS(13))                                         DK311460
   66 CONTINUE                                                          DK311470
***  RETRIEVE ABSORPTIVITIES (SOLAR AND AVERAGE PLANET)                 DK311480
   50 DO 51 I=1,NSATP                                                   DK311490
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      XLAMB(I)=ELAMB(I)*57.29578                                        DK311500
      XMEGA(I)=OMEGA(I)*57.29578                                        DK311510
      JC= NCOAT(I)                                                      DK311520
      AS(I)=ESUN(JC)                                                    DK311530
      BRITE(I)= HALB(I)                                                 DK311540
   51 DARK(I)= HSUN(I)                                                  DK311550
      JT=LAST                                                           DK311560
      RUN=NUMRUN                                                        DK311570
   10 IF (NQORT*NQORT -2*NQORT)12,13,12                                 DK311580
   13 IGO= -1                                                           DK311590
      GO TO 15                                                          DK311600
   12 IGO= 0                                                            DK311610
   15 CONTINUE                                                          DK311620
      DO 19 II=1,LMAX                                                   DK311630
   19 PHIO(II)=PHIPLT(II)                                               DK311640
***  PHIZ2 IS THE INITIAL TRUE ANOMALY VALUE                            DK311650
      IF(PHIZ2-.01)31,31,32                                             DK311660
   32 NSWTCH=1                                                          DK311670
      GO TO 18                                                          DK311680
   31 NSWTCH=0                                                          DK311690
   18 CONTINUE                                                          DK311700
      NFIRST=0                                                          DK311710
      N30=0                                                             DK311720
      DO 5 I=1,NSATP, 2                                                 DK311730
      REWIND JT                                                         DK311740
      JJ= I                                                             DK311750
      KK=I+1                                                            DK311760
      DO 20 L=1,LMAX                                                    DK311770
***  READ BINARY SCRATCH TAPE JT TO OBTAIN INFORMATION RECORDED BY      DK311780
***          SUBROUTINE LOOP IN LINK 1                                  DK311790
***  INFORMATION WILL BE RETRIEVED TWO(2) NODES PER PASS                DK311800
      READ   (JT)(TX(1,J),HSUN(J),HALB(J),HPLAN(J),HASUN(J),HAALB(J), HAPDK311810
     1LN(J),HATOT(J),J=1,NSATP )                                        DK311820
      IF( IGO ) 25,30,30                                                DK311830
***  RETRIEVE INCIDENT HEATS                                            DK311840
   25 S1(L)=HSUN(JJ)                                                    DK311850
      S2(L)=HSUN(KK)                                                    DK311860
      A1(L)=HALB(JJ)                                                    DK311870
      A2(L)=HALB(KK)                                                    DK311880
      P1(L)=HPLAN(JJ)                                                   DK311890
      P2(L)=HPLAN(KK)                                                   DK311900
      GO TO 16                                                          DK311910
***  RETRIEVE ABSORBED HEATS                                            DK311920
   30 S1(L)=HASUN(JJ)                                                   DK311930
      S2(L)=HASUN(KK)                                                   DK311940
      A1(L)=HAALB(JJ)                                                   DK311950
      A2(L)=HAALB(KK)                                                   DK311960
      P1(L)=HAPLN(JJ)                                                   DK311970
      P2(L)=HAPLN(KK)                                                   DK311980
      Q1(L)=HATOT(JJ)                                                   DK311990
      Q2(L)=HATOT(KK)                                                   DK312000
   16 IF(NQORT*NQORT-3*NQORT)17,20,17                                   DK312010
   17 T1(L)= TX(1,JJ)                                                   DK312020
      T2(L)= TX(1,KK)                                                   DK312030
      N30=1                                                             DK312040
   20 CONTINUE                                                          DK312050
      IF(N30)40,40,35                                                   DK312060
   35 IF(NSWTCH)40,40,45                                                DK312070
 **  ARRANGE TRUE ANOMALY ARRAY (PHIPLT) IN ASCENDING ORDER IF NOT      DK312080
      ALREADY IN SUCH FORM (WILL NOT BE ASCENDING WHEN PHIZ NOT =0.0 )  DK312090
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45 CALL ACCEND(PHIO(1),PHIPLT(1),T1(1),T2(1),LMAX)                  DK312100
40 CONTINUE                                                          DK312110
** SUBROUTINE DRAW CONSTRUCTS IDENTIFIED PLOTS OF HEATS              DK312120
**          AND/OR TEMPERATURES                                      DK312130
** NODES ARE PLOTTED TWO (2) AT A TIME                               DK312140
   CALL DRAW(NODE,PHIPLT,TIMPLT,S1,S2,A1,A2,P1,P2,Q1,Q2,T1,T2,       DK312150
  1PHIO,PNAME,IMTHRU,XLAMB,XMEGA,AS,BRITE,DARK,ZAREA,THATS,ALL,FOLKS,DK312160
  2LMAX,KETCH,NQORT,NSATP,KABG)                                      DK312170
 5 CONTINUE                                                          DK312180
   JUMP=2                                                            DK312190
   CALL FILMAV(1)                                                    DK312200
   CALL CLOCK(TYME2)                                                 DK312210
** RETURN TO PILOT IN LINK 1 WITH JUMP =2                            DK312220
   RETURN                                                            DK312230
   END                                                               DK312240


    FOR      DECK32,DECK32                                           DK320000
   SUBROUTINE DRAW(NODE,PHIPLT,TIMPLT,S1,S2,A1,A2,P1,P2,Q1,Q2,T1,T2, DK320010
  1PHIO,PNAME,IMTHRU,ELAMB,OMEGA,AS,BRITE,DARK,ZAREA,THATS,ALL,FOLKS,DK320020
  2LMAX,KETCH,NQORT,NSATP,KABG)                                      DK320030
   DIMENSION T1(190),T2(190) ,TELL1( 7),TELL2( 7),RL(9)              DK320040
   DIMENSION NODE(200),IMTHRU(200), PHIPLT(190),TIMPLT(190),S1(190), DK320050
  1S2(190),A1(190),A2(190),P1(190),P2(190),Q1(190),Q2(190)           DK320060
   DIMENSION TELL(7),PNAME(39)                                       DK320070
   DIMENSION S(190),A(190),P(190),Q(190)                             DK320080
   DIMENSION XNAME1(13),XNAME2(13),XNAME3(13)                        DK320090
   DIMENSION TOP(4),BOT(4) ,YL(9),TL(9),PL(9)                        DK320100
   DIMENSION YNAM (5),TANOM(2) ,YTEMP(4)                             DK320110
   DIMENSION PHIO(190),TAN(9),LOC(9),NC(9),BCD(9)                    DK320120
   DIMENSION AS(200),BRITE(200),DARK(200),ZAREA(200)                 DK320130
   DIMENSION ACROSS(19) ,ELAMB(200),OMEGA(200)                       DK320140
   DIMENSION THATS(16),ALL(20),FOLKS(13)                             DK320150
   COMMON/BLJK/IGO,JJ,KK,RUN,NFIRST,NALL,ALL1,NALL1                  DK320160
   NONE=NFIRST                                                       DK320170
   IF (NFIRST) 2,2,1                                                 DK320180
** THE INSTRUCTIONS FROM HERE TO STATEMENT NO. 1 ARE REACHED ONCE    DK320190
    IN EACH CASE                                                     DK320200
 2 NFIRST =1                                                         DK320210
   DO 3 I=1,13                                                       DK320220
 3 XNAME1(I)=PNAME(I)                                                DK320230
   DO 4 I=1,13                                                       DK320240
 4 XNAME2(I)=PNAME(I+13)                                             DK320250
   DO 5 I=1,13                                                       DK320260
 5 XNAME3(I)=PNAME(I+26)                                             DK320270
** SET UP BCD SENTENCES TO BE WRITTEN AS PLOT IDENTIFICATION         DK320280
   DATA Q000HL/6HTEMPER/                                             DK320290
   YTEMP(1)=Q000HL                                                   DK320300
   DATA Q001HL/6HATURE /                                             DK320310
   YTEMP(2)=Q001HL                                                   DK320320
   DATA Q002HL/6HDEG. R/                                             DK320330
   YTEMP(3)=Q002HL                                                   DK320340
   DATA Q003HL/6HRANKINE/                                            DK320350
   YTEMP(4)=Q003HL                                                   DK320360
   DATA Q000CT/0310506232422/                                        DK320370
   TANOM(1)=Q000CT                                                   DK320380
   DATA Q001CT/0750505050505/                                        DK320390
   TANOM(2)=Q001CT                                                   DK320400
   DATA Q004HL/6HNODE N/                                             DK320410
   TELL(1)=Q004HL                                                    DK320420
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      DATA Q005HL/6HUMBER /                                             DK320430
      TELL(2)=Q005HL                                                    DK320440
      DATA Q006HL/6HCASE N/                                             DK320450
      TELL(4)=Q006HL                                                    DK320460
      TELL(5)=Q005HL                                                    DK320470
      DATA Q007HL/6H     L/                                             DK320480
      ACROSS(1)=Q007HL                                                  DK320490
      DATA Q008HL/6HAMBDA=/                                             DK320500
      ACROSS(2)=Q008HL                                                  DK320510
      DATA Q009HL/6H OMEG=/                                             DK320520
      ACROSS(4)=Q009HL                                                  DK320530
      IF(NQORT-3)70,71,71                                               DK320540
      DATA Q010HL/6H PLANE/                                             DK320550
   71 ACROSS( 6)=Q010HL                                                 DK320560
      DATA Q011HL/6HT ABS(/                                             DK320570
      ACROSS( 7)=Q011HL                                                 DK320580
      DATA Q012HL/6HSUN) =/                                             DK320590
      ACROSS( 8)=Q012HL                                                 DK320600
      DATA Q013HL/6H PLNET/                                             DK320610
      ACROSS(10)=Q013HL                                                 DK320620
      DATA Q014HL/6H ABS(S/                                             DK320630
      ACROSS(11)=Q014HL                                                 DK320640
      DATA Q015HL/6HHADE)=/                                             DK320650
      ACROSS(12)=Q015HL                                                 DK320660
      DATA Q016HL/6H SOLAR/                                             DK320670
      ACROSS(14)=Q016HL                                                 DK320680
      DATA Q017HL/6H ABS =/                                             DK320690
      ACROSS(15)=Q017HL                                                 DK320700
      DATA Q018HL/6H SURFA/                                             DK320710
      ACROSS(17)=Q018HL                                                 DK320720
      DATA Q019HL/6HCE A.=/                                             DK320730
      ACROSS(18)=Q019HL                                                 DK320740
   70 NTOP=30                                                           DK320750
C***  CONVERT RUN NO. TO BCD                                            DK320760
      CALL BINDEC (RUN,NCRUN,TELL(6),DUMMY)                             DK320770
      TELL(6)=FDTA(TELL(6))                                             DK320780
      IF(NQORT* NQORT -2*NQORT )25,24,25                                DK320790
      DATA Q020HL/6HABSORB/                                             DK320800
   25 YNAM(1) = Q020HL                                                  DK320810
      DATA Q021HL/6HED    /                                             DK320820
      YNAM(2) = Q021HL                                                  DK320830
      GO TO 26                                                          DK320840
      DATA Q022HL/6HINCIDE/                                             DK320850
   24 YNAM(1) =Q022HL                                                   DK320860
      DATA Q023HL/6HNT    /                                             DK320870
      YNAM(2) =Q023HL                                                   DK320880
      DATA Q024HL/6H HEAT,/                                             DK320890
   26 YNAM(3) =Q024HL                                                   DK320900
      DATA Q025HL/6HBTU/HR/                                             DK320910
      YNAM(4)=Q025HL                                                    DK320920
      IF (KETCH)27,28,27                                                DK320930
      DATA Q026HL/6H FT**2/                                             DK320940
   28 YNAM(5 ) =Q026HL                                                  DK320950
      GO TO 29                                                          DK320960
      DATA Q027HL/6H....../                                             DK320970
   27 YNAM(5 ) =Q027HL                                                  DK320980
   29 CONTINUE                                                          DK320990
      XMIN=0.0                                                          DK321000
      XMAX=TIMPLT(LMAX)                                                 DK321010
      IL(1)=TIMPLT(1)                                                   DK321020
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      TL(9)=XMAX                                                        DK321030
      DEL=(XMAX-XMIN)/8.0                                               DK321040
      TL(2)=DEL                                                         DK321050
      DO 6 I=3,8                                                        DK321060
      IX=I-1                                                            DK321070
    6 TL(I)=TL(IX)+DEL                                                  DK321080
*** SKALE DETERMINES A SUITABLE MAX,MIN, AND 7 VALUES IN BETWEEN        DK321090
      CALL SKALE (PHIPLT(LMAX),PHIPLT(1),PL(1),PL(2),PL(3),PL(4),PL(5), DK321100
     1PL(6),PL(7),PL(8),PL(9) )                                         DK321110
      PMIN= PL(1)                                                       DK321120
      PMAX= PL(9)                                                       DK321130
    1 IF(NQORT-1)11,100,11                                              DK321140
   11 CONTINUE                                                          DK321150
*** BEGIN PLOT SCHEME , STARTING WITH ELEMENT JJ                        DK321160
      IFIRST=1                                                          DK321170
      INODE=JJ                                                          DK321180
      DO 10 I=1,LMAX                                                    DK321190
      S(I)=S1(I)                                                        DK321200
      A(I)=A1(I)                                                        DK321210
      P(I)=P1(I)                                                        DK321220
   10 Q(I)=Q1(I)                                                        DK321230
   15 CALL RSET(1)                                                      DK321240
*** DETERMINE LIMITS OF HEAT ARRAYS                                     DK321250
      CALL HILOW(S(1),LMAX,TOP(1),BOT(1) )                              DK321260
      CALL HILOW(A(1),LMAX,TOP(2),BOT(2) )                              DK321270
      CALL HILOW(P(1),LMAX,TOP(3),BOT(3) )                              DK321280
      IF(IGO)16,17,17                                                   DK321290
   17 CALL HILOW(Q(1),LMAX,QMAX,BOT(4))                                 DK321300
      CALL HILOW(BOT(1),4,DUM,QMIN)                                     DK321310
      GO TO 18                                                          DK321320
   16 BOT(4)=10000.0                                                    DK321330
      TOP(4)=0.0                                                        DK321340
      CALL HILOW(TOP(1),4,QMAX,DUM)                                     DK321350
      CALL HILOW(BOT(1),4,DUM,QMIN)                                     DK321360
   18 CONTINUE                                                          DK321370
*** SKALE DETERMINES A SUITABLE MAX,MIN, AND 7 VALUES IN BETWEEN        DK321380
      CALL SKALE(QMAX,QMIN,YL(1),YL(2),YL(3),YL(4),YL(5),YL(6),YL(7),   DK321390
     1 YL(8),YL(9)  )                                                   DK321400
      QMIN=YL(1)                                                        DK321410
      QMAX=YL(9)                                                        DK321420
*** GENERATE GRID AND PLOT HEATS                                        DK321430
      CALL GRIDGN (63,1023,0,960,12,12,10,10 )                          DK321440
      CALL PLOT1 (1,1,XMIN,XMAX,QMIN,QMAX,TIMPLT(1),S(1),LMAX,1,1HS)    DK321450
      CALL PLOT1 (1,1,XMIN,XMAX,QMIN,QMAX,TIMPLT(1),A(1),LMAX,1,1HA)    DK321460
      CALL PLOT1 (1,1,XMIN,XMAX,QMIN,QMAX,TIMPLT(1),P(1),LMAX,1,1HP)    DK321470
      IF( IGO )30,20,20                                                 DK321480
   20 CALL PLOT1 (1,1,XMIN,XMAX,QMIN,QMAX,TIMPLT(1),Q(1),LMAX,1,1HQ)    DK321490
   30 IF(NONE)93,94,93                                                  DK321500
   94 DO 7 I=1,9                                                        DK321510
*** FIND TRUE ANOMALY (TAN(I)) CORRESPONDING TO TIME TL(I)              DK321520
      CALL XINTRP(LMAX,TIMPLT(1),TL(I),PHIO(1),TAN(I)  )                DK321530
*** CONVERT EACH TAN(I) (TRUE ANOMALY) TO BCD EQUIVALENT                DK321540
      IF(TAN(I))44,43,44                                                DK321550
      DATA QU02CT/0050505050505/                                        DK321560
   43 BCD(I)=QU02CT                                                     DK321570
      GO TO 8                                                           DK321580
   44 CALL BINDEC(TAN(I),NC(I),BCD(I),DUMMY)                            DK321590
      BCD(I)=FDTA(BCD(I))                                               DK321600
      DUMMY=FDTA(DUMMY)                                                 DK321610
    8 NC(I)=6                                                           DK321620
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C *** FIND LOCATION OF TL(I) IN RASTER COUNTS
      LTEMP=SCALEX(TL(I),1)
      LOC(I)=LTEMP-21
    7 CONTINUE
      LOC(9)=LOC(9)-22
C *** PUT LABELS AND IDENTIFICATION ON THE PRESENT FRAME
   93 DO 95 I=1,9
      CALL PRINT(LOC(I),981,8,0,NC(I),BCD(1))
      CALL LABELY(YL(I),1,0)
   95 CALL LABELX(TL(I),1,0)
      CALL PRINT(63,1003, 8,0,78,XNAME1(1))
      CALL PRINT(63,1013, 8,0,78,XNAME2(1))
      CALL PRINT(63,1023, 8,0,78,XNAME3(1))
      CALL PRINT( 1,360,0,12,30,YNAM(1))
      CALL PRINT( 1,970,8,0,6,6HMIN.      )
      CALL PRINT( 1,981,8,0,12,TANOM(1))
      CALL BINDEC(ELAMB(INODE),NDUM,ACROSS( 3),DUM)
      ACROSS(3)=FDTA(ACROSS(3))
      DUM=FDTA(DUM)
      CALL BINDEC(OMEGA(INODE),NDUM,ACROSS( 5),DUM)
      ACROSS(5)=FDTA(ACROSS(5))
      IF(NQORT-3)75,73,73
   73 CALL BINDEC(BRITE(INODE),NDUM,ACROSS( 9),DUM)
      ACROSS(9)=FDTA(ACROSS(9))
      CALL BINDEC( DARK(INODE),NDUM,ACROSS(13),DUM)
      ACROSS(13)=FDTA(ACROSS(13))
      CALL BINDEC(    AS(INODE),NDUM,ACROSS(16),DUM)
      ACROSS(16)=FDTA(ACROSS(16))
      NTOP=96
      IF(ZAREA(INODE))74,75,74
   74 CALL BINDEC(ZAREA(INODE),NDUM,ACROSS(19),DUM)
      ACROSS(19)=FDTA(ACROSS(19))
      NTOP=114
   75 CONTINUE
      CALL PRINT( 70, 8,8,0, NTOP,ACROSS(1))
      CALL PRINT(138,20,8,0,    96,THATS(1))
      CALL PRINT( 63,32,8,0, NALL,ALL(1))
      CALL PRINT( 67,32,7,0, NALL1,ALL1   )
      IF(KARG)76,77,76
   76 CALL PRINT(231,44,8,0,  78,FOLKS(1))
   77 CONTINUE
      IF(IFIRST-1)54,54,55
   54 XNODE=NODE(JJ)
      GO TO 56
   55 XNODE=NODE(KK)
C *** CONVERT NODE NO. TO BCD AND WRITE A SENTENCE INCLUDING SAME
   56 CALL BINDEC (XNODE,NCNODE,TELL(3),DUMMY )
      TELL(3)=FDTA(TELL(3))
      NCHAR=12+ NCNODE
      CALL PRINT( 63,992,12,0,NCHAR,TELL(1))
      NCHAR=12+ NCRUN
      CALL PRINT(280,992,12,0,NCHAR,TELL(4))
C *** TERMINATE THIS PLOT AND PROCEED
      CALL DMPBUF
      IF(IFIRST-1)41,41,42
   42 TELL2(4)=TELL(3)
      GO TO 60
   41 TELL1(4)=TELL(3)
      DO 50 I=1,LMAX
      S(I)=S2(I)
```

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      A(I)=A2(I)                                                         DK322230
      P(I)=P2(I)                                                         DK322240
   50 Q(I)=Q2(I)                                                         DK322250
      IFIRST = 2                                                         DK322260
      NONE=1                                                             DK322270
      INODE= KK                                                          DK322280
      IF(INODE-NSATP)15,15,60                                            DK322290
   60 IF(NQORT*NQORT- 3*NQORT )100,102,100                               DK322300
  100 IF(IMTHRU(JJ)+IMTHRU(KK) )104,102,104                              DK322310
C *** PLOT STABILIZED TEMPERATURES OF ELEMENTS JJ AND KK IF REQUIRED     DK322320
  104 CALL HILOW (T1(1),LMAX,T1MAX,T1MIN)                                DK322330
      CALL HILOW (T2(1),LMAX,T2MAX,T2MIN )                               DK322340
      TMAX= AMAX1(T1MAX,T2MAX)                                           DK322350
      TMIN= AMIN1(T1MIN,T2MIN)                                           DK322360
C *** SKALE DETERMINES A SUITABLE MAX,MIN, AND 7 VALUES IN BETWEEN       DK322370
      CALL SKALE (TMAX,TMIN,RL(1),RL(2),RL(3),RL(4),RL(5),RL(6),RL(7),   DK322380
     1RL(8),RL(9) )                                                      DK322390
C *** GENERATE GRID THEN PLOT STABILIZED TEMPERATURES AND IDENTIFY       DK322400
      CALL RSET(1)                                                       DK322410
      CALL GRIDGN (63,1023,0,960,12,12,10,10 )                           DK322420
      IF(IMTHRU(JJ))67,67,68                                             DK322430
   68 CALL PLOT1 (1,1,PMIN,PMAX,RL(1),RL(9),PHIPLT(1),T1(1),LMAX,1,1H1 )DK322440
   67 IF(IMTHRU(KK))66,66,69                                             DK322450
   69 IF(KK-NSATP)65,65,66                                               DK322460
   65 CALL PLOT1 (1,1,PMIN,PMAX,RL(1),RL(9),PHIPLT(1),T2(1),LMAX,1,1H2 )DK322470
C *** TIDENT CONSTRUCTS SENTENCES TELL1 AND TELL2 WHICH DESCRIBE         DK322480
C *** TEMPERATURE CURVES                                                 DK322490
   66 CALL TIDENT (JJ,KK,IMTHRU(1),TELL1(1),TELL2(1),NSATP,NCJJ,NCKK)    DK322500
      DO 101 I=1,9                                                       DK322510
      CALL LABELY(RL(I),1,0)                                             DK322520
  101 CALL LABELX(PL(I),1,0)                                             DK322530
      NNC= 18+ NCNODE                                                    DK322540
      CALL PRINT( 63,981, 8,0,NNC,TELL1(1))                              DK322550
      NCO=  6+ NCJJ                                                      DK322560
      CALL PRINT(255,981, 8,0,NCO   ,TELL1(5))                           DK322570
      CALL PRINT(351,981, 8,0,     6,TELL1(7))                           DK322580
      CALL PRINT( 63,992, 8,0,NNC,TELL2(1))                              DK322590
      NCO=  6+ NCKK                                                      DK322600
      CALL PRINT(255,992, 8,0,NCO,TELL2(5))                              DK322610
      CALL PRINT(351,992, 8,0,  6,TELL2(7))                              DK322620
      CALL PRINT(63,1003, 8,0,78,XNAME1(1))                              DK322630
      CALL PRINT(63,1013, 8,0,78,XNAME2(1))                              DK322640
      CALL PRINT(63,1023, 8,0,78,XNAME3(1))                              DK322650
      CALL PRINT( 1,969,8,0,12,TANOM(1))                                 DK322660
      CALL PRINT(10,365,0,12,24,YTEMP(1))                                DK322670
C *** TERMINATE THIS PLOT AND RETURN TO MAIN2 WHERE WE WILL OBTAIN       DK322680
C *** INFORMATION PERTAINING TO THE NEXT TWO ELEMENTS                    DK322690
      CALL DMPBUF                                                        DK322700
  102 RETURN                                                             DK322710
      END                                                                DK322720
*      FOR      DECK33,DECK33                                            DK330000
      SUBROUTINE SKALE(TOP,BOTTOM,A,B,C,D,E,F,G,H,XI)                    DK330010
CSKALE                                                                   DK330020
C        TRUNCATE,ROUND AND FLOAT, INSERT 7 VALUES BETWEEN 2 GIVEN VALUEDK330030
C        TOP = GIVEN TOP VALUE(MAX)                                      DK330040
C     BOTTOM = GIVEN BOTTOM VALUE(MIN)                                   DK330050
C          A = SCALED MINIMUM                                            DK330060
C          B = INSERTED VALUE 1                                          DK330070
C          C = INSERTED VALUE 2                                          DK330080
C          D = INSERTED VALUE 3                                          DK330090
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C           E = INSERTED VALUE 4                                        DK330100
C           F,G,H, AND XI ARE INSERTED AT PROPER LOCATION               DK330110
      FINC=TOP-BOTTOM                                                   DK330120
      AST = ALOG(FINC)/ALOG(10.0)                                       DK330130
      IF (AST) 5,10,10                                                  DK330140
    5 AST=AST-1.0                                                       DK330150
   10 NAST=AST                                                          DK330160
      P10AST=10.0**NAST                                                 DK330170
      FMAX=P10AST*(AINT(TOP/P10AST)+1.0)                                DK330180
      FMIN=P10AST*AINT(BOTTOM/P10AST)                                   DK330190
      IF(BOTTOM)15,20,20                                                DK330200
   15 FMIN=FMIN-P10AST                                                  DK330210
      IF (TOP) 17,20,20                                                 DK330220
   17 TOP = TOP - P10AST                                                DK330230
   20 SC=(FMAX-FMIN)/8.0                                                DK330240
      A=FMIN                                                            DK330250
      B=A+SC                                                            DK330260
      C=B+SC                                                            DK330270
      D=C+SC                                                            DK330280
      E=D+SC                                                            DK330290
      F=E+SC                                                            DK330300
      G=F+SC                                                            DK330310
      H=G+SC                                                            DK330320
      XI=FMAX                                                           DK330330
      RETURN                                                            DK330340
      END                                                               DK330350


       FOR      DECK34,DECK34                                           DK340000
      SUBROUTINE XINTRP(N,A,AA,B,BB)                                    DK340010
      DIMENSION  A(182), B(182)                                         DK340020
      DO 100 I=1,N                                                      DK340030
      K=I                                                               DK340040
      IF(AA-A(I))1,2,100                                                DK340050
  100 CONTINUE                                                          DK340060
      BB=0.0                                                            DK340070
      GO TO 5                                                           DK340080
    2 BB=B(K)                                                           DK340090
      GO TO 5                                                           DK340100
    1 X=((AA-A(K-1))*(B(K)-B(K-1)))/(A(K)-A(K-1))                       DK340110
      BB=B(K-1)+X                                                       DK340120
    5 RETURN                                                            DK340130
      END                                                               DK340140


       FOR      DECK35,DECK35                                           DK350000
      SUBROUTINE ACCEND(XO,X,Y,Z,N)                                     DK350010
C *** ARRANGE X,Y, AND Z IN ORDER OF INCREASING X VALUES BUT KEEP       DK350020
  ***ORIGINAL ORDER OF X ARRAY IN XO                                    DK350030
      DIMENSION X(1),Y(1) ,Z(1)                                         DK350040
      DIMENSION XO(1)                                                   DK350050
      DO 104 J=1,N                                                      DK350060
  104 X(J)=XO(J)                                                        DK350070
      K=1                                                               DK350080
  101 SMALL=X(K)                                                        DK350090
      DO 100 I=K,N                                                      DK350100
      DUMY=X(I)                                                         DK350110
      SMALL=AMIN1(SMALL,DUMY)                                           DK350120
      IF(SMALL-X(I))100,102,100                                         DK350130
  102 INDEX=I                                                           DK350140
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100 CONTINUE                                                            DK350150
    X(INDEX)=X(K)                                                       DK350160
    X(K)=SMALL                                                          DK350170
    SAVE=Y(K)                                                           DK350180
    Y(K)=Y(INDEX)                                                       DK350190
    Y(INDEX)=SAVE                                                       DK350200
    SAVEZ=Z(K)                                                          DK350210
    Z(K)=Z(INDEX)                                                       DK350220
    Z(INDEX)=SAVEZ                                                      DK350230
    K=K+1                                                               DK350240
    IF(K-N)101,103,101                                                  DK350250
103 RETURN                                                              DK350260
    END                                                                 DK350270


     FOR      DECK36,DECK36                                             DK360000
    SUBROUTINE HILOW(TABLE,NPTS,XHI,XLO)                                DK360010
    DIMENSION TABLE(1)                                                  DK360020
    XLO=TABLE(1)                                                        DK360030
    XHI=TABLE(1)                                                        DK360040
    DO 10 I=2,NPTS                                                      DK360050
    XLO=AMIN1(XLO,TABLE(I)   )                                          DK360060
 10 XHI=AMAX1(XHI,TABLE(I)   )                                          DK360070
    RETURN                                                              DK360080
    END                                                                 DK360090


     FOR      DECK37,DECK37                                             DK370000
    SUBROUTINE TIDENT (JJ,KK,IMTHRU,TELL1,TELL2,NSATP,NCJJ,NCKK)        DK370010
*** TIDENT CONSTRUCTS SENTENCES TELL1 AND TELL2 WHICH DESCRIBE          DK370020
*** TEMPERATURE CURVES                                                  DK370030
    DIMENSION TELL1(7),TELL2(7),IMTHRU(200)                             DK370040
    DATA II/0050505050505/                                              DK370050
    DATA T5/6HCURVE /                                                   DK370060
    DATA T6/6H1 = EL/                                                   DK370070
    DATA T7/5HEMENT /                                                   DK370080
    DATA T8/5HAFTER /                                                   DK370090
    DATA T9/6HORBITS/                                                   DK370100
    DATA T10/6H2 = EL/                                                  DK370110
    IF(IMTHRU(JJ))10,10,20                                              DK370120
 10 DO 15 I=1,7                                                         DK370130
 15 TELL1(I)=II                                                         DK370140
    GO TO 30                                                            DK370150
 20 TELL1(1)=T5                                                         DK370160
    TELL1(2)=T6                                                         DK370170
    TELL1(3)=T7                                                         DK370180
    TELL1(5)=T8                                                         DK370190
    TELL1(7)=T9                                                         DK370200
 30 IF(IMTHRU(KK))40,40,50                                              DK370210
 40 DO 45 I=1,7                                                         DK370220
 45 TELL2(I)=II                                                         DK370230
    GO TO 60                                                            DK370240
 50 TELL2(1)=T5                                                         DK370250
    TELL2(2)=T10                                                        DK370260
    TELL2(3)=T7                                                         DK370270
    TELL2(5)=T8                                                         DK370280
    TELL2(7)=T9                                                         DK370290
 60 IF(IMTHRU(JJ)+IMTHRU(KK))61,70,61                                   DK370300
 61 HORBIT=I1                                                           DK370310
    NELMT=JJ                                                            DK370320
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67 IF(IMTHRU(NELMT))63,63,62                                    DK370330
62 ORBIT=IMTHRU(NELMT)                                          DK370340
   CALL BINDEC (ORBIT,NC,HORBIT,DUMMY)                          DK370350
   HORBIT=FDTA(HORBIT)                                          DK370360
63 IF(NELMT-JJ)65,65,66                                         DK370370
65 TELL1(6)=HORBIT                                              DK370380
   NCJJ=NC                                                      DK370390
   NELMT=KK                                                     DK370400
   HORBIT=I1                                                    DK370410
   GO TO 67                                                     DK370420
66 TELL2(6)=HORBIT                                              DK370430
   NCKK=NC                                                      DK370440
70 RETURN                                                       DK370450
   END                                                          DK370460


    FOR      DECK38,DECK38                                      DK380000
   INTEGER FUNCTION FDTA(WORD)                                  DK380010
   INTEGER WORD                                                 DK380020
   DATA MASK/000000000077/                                      DK380030
   J = 0                                                        DK380040
   DO 1 I=1,6                                                   DK380050
   N = WORD/2**(36-6*I)                                         DK380060
   N = AND(N,MASK)                                              DK380070
   IF (N .LE. 9)GO TO 2                                         DK380080
   GO TO 5                                                      DK380090
 2 N = N + 48                                                   DK380100
   GO TO 6                                                      DK380110
 5 IF ( N.EQ. 27) N= 61                                         DK380120
   IF( N .EQ.32) N=33                                           DK380130
   IF (N .EQ. 48) N=5                                           DK380140
 6 J = OR(J*2**6,N)                                             DK380150
 1 CONTINUE                                                     DK380160
   FDTA = J                                                     DK380170
   RETURN                                                       DK380180
   END                                                          DK380190
```

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